BACHELOR THESIS & COLLOQUIUM – ME 141502

APPLICATION OF RELIABILITY-CENTERED MAINTENANCE (RCM) METHOD FOR FUEL OIL SYSTEM ON MV. KENDARI I PT MERATUS LINE

DIMAS DARMAWAN
NRP. 04211441000002

SUPERVISOR :
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DOUBLE DEGREE PROGRAM
DEPARTEMENT OF MARINE ENGINEERING
FACULTY OF MARINE TECHNOLOGY
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
SURABAYA

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SKRIPSI – ME 141502

APLIKASI DARI METODE RELIABILITY-CENTERED MAINTENANCE (RCM) UNTUK SISTEM BAHAN BAKAR DI MV. KENDARI I PT MERATUS LINE

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APPROVAL FORM

APPLICATION OF RELIABILITY-CENTERED MAINTENANCE (RCM) METHOD FOR FUEL OIL SYSTEM ON MV. KENDARI I PT MERATUS LINE

BACHELOR THESIS

Submitted to Comply One of The Requirement to Obtain a Bachelor Engineering Degree
on
Reliability, Availability, Management and Safety (RAMS)
Bachelor Program Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

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Representative of Hochschule Wismar in Indonesia

Dr.-Ing. Wolfgang Busse

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DECLARATION OF HONOR

I hereby who signed below declare that :

This bachelor thesis has written and developed independently without any plagiarism act, and confirm consciously that all data, concepts, design, references, and material in this report own by Reliability, Availability, Management and Safety (RAMS) in Department of Marine Engineering ITS which are the product of research study and reserve the right to use for further research study and its development.

Name	: Dimas Darmawan
NRP	: 04211441000002
Bachelor Thesis Title	: Application of Reliability-Centered Maintenance (RCM) Method for Fuel Oil System on MV. Kendari I PT Meratus Line
Department	: Marine Engineering

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Surabaya, December 2017

Dimas Darmawan

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APPLICATION OF RELIABILITY-CENTERED MAINTENANCE (RCM) METHOD FOR FUEL OIL SYSTEM ON MV. KENDARI I PT MERATUS

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ABSTRACT

Reliability-Centered Maintenance (RCM) is one of the processes that use to decisive action which should be performed to ensure any physical components or a system be able to work optimally in accordance with the function desired by its users. Basically, RCM used a risk management principles of the component failure, so that the type of maintenance can be determined properly. By using an approriate type of maintenance, the posibbility failures in a component can be detected and prevented earlier. A proper use of RCM be able to give a positive impact on cost savings, both maintenance costs and repair costs as the consequence of failures.

In this final project, the system which become the object of research is the fuel oil system on MV. Kendari I which belongs to PT Meratus Line. The fuel oil system is extremely important system on a ship which is designed to supply clean fuel oil to main engine, diesel generators and emergency diesel generator. Container vessel is one of the main assets of PT Meratus Line which support the company income. Therefore, improving the efficiency of operating activity is an important action to be done by the company. Determining prority levels about the failure components which have critical consequences can be done through the RCM process. Thus it results on the well planed and efficient maintenance system.

Based on the results of this final project, there were 43 tasklist type which is obtained based on the analysis of maintenance task allocation and planning. The percentage of maintenance types from each failure mode (task type) as follows Preventive Maintenance (PM) is 41,8%, Condition Monitoring (CM) is 30,2%, Failure Finding (FF) is 27,9%. For the optimum cost maintenace from each component as follows HFO Transfer Pump has tp is worth 3500 hours with minimum estimated cost of Rp. 346.017,00, MDO Transfer Pump has tp is worth

3500 hours with minimum estimated cost of Rp. 363.019,00, Separator has tp is worth 1700 hours with minimum estimated cost of Rp. 518.342,00, Heater has tp is worth 4400 hours with minimum estimated cost of Rp. 31.354,00, HFO Feeder Pump has tp is worth 3500 hours with minimum estimated cost of Rp. 350.380,00, HFO Circulating Pump has tp is worth 3500 hours with minimum estimated cost of Rp. 346.017,00, Filter has tp is worth 4800 hours with minimum estimated cost of Rp. 30.619,00, Main Engine Injection Pump has tp is worth 2200 hours with minimum estimated cost of Rp. 792.632,00, Main Engine Injection Valve has tp is worth 1700 hours with minimum estimated cost of Rp. 755.806,00.

Keyword : Container Vessel, RCM, FMECA, Maintenance Task Allocation and Planning, Maintenance Cost

APLIKASI DARI METODE RELIABILITY-CENTERED MAINTENANCE (RCM) UNTUK SISTEM BAHAN BAKAR DI MV. KENDARI I PT MERATUS LINE

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ABSTRAK

Reliability-Centered Maintenance (RCM) merupakan salah satu proses yang dijalankan dalam menentukan tindakan yang seharusnya dilakukan untuk menjamin setiap komponen fisik atau suatu sistem dapat berjalan secara optimal sesuai dengan fungsi yang diinginkan oleh penggunanya. RCM menjalankan prinsip manajemen resiko dari kegagalan komponen sehingga tipe perawatan dapat ditentukan dengan tepat. Dengan menggunakan tipe perawatan yang tepat, maka kegagalan yang mungkin terjadi dapat terdeteksi dan dicegah sejak awal. Penggunaan yang tepat pada RCM dapat memberikan dampak pada penghematan biaya, baik biaya perawatan maupun biaya perbaikan akibat terjadinya kegagalan.

Dalam tugas akhir ini, sistem yang menjadi objek penelitian adalah sistem bahan bakar minyak pada MV. Kendari I milik PT Meratus Line. Sistem bahan bakar minyak merupakan sistem yang sangat penting di kapal yang dirancang untuk memasok bahan bakar minyak bersih ke mesin utama, generator diesel dan generator diesel darurat. Kapal Kontainer adalah salah satu aset utama PT Meratus Line yang menunjang pendapatan perusahaan. Oleh karena itu, meningkatkan efisiensi kegiatan operasi merupakan tindakan penting yang harus dilakukan oleh perusahaan. Menentukan tingkat proritas pada kegagalan komponen yang memiliki konsekuensi kritis dapat dilakukan melalui proses RCM. Sehingga menghasilkan sistem perawatan yang terencana dan efisien.

Berdasarkan hasil tugas akhir ini, terdapat 43 jenis daftar tugas yang diperoleh berdasarkan analisis alokasi dan perencanaan tugas pemeliharaan. Persentase tipe perawatan dari masing-masing mode kegagalan (tipe tugas) sebagai berikut Preventive Maintenance (PM) adalah 41,8%, Condition Monitoring (CM) adalah 30,2%, Failure Finding (FF) adalah 27,9%. Untuk pemeliharaan biaya optimal dari masing-masing komponen sebagai berikut Pompa Transfer HFO memiliki tp 3500 jam dengan estimasi biaya minimal Rp. 346.017,00, Pompa Transfer MDO memiliki tp seharga 3500 jam dengan estimasi biaya minimal Rp. 363.019,00, Separator memiliki tp 1700 jam dengan estimasi biaya minimal Rp. 518.342,00, Pemanas memiliki tp 4400 jam dengan estimasi biaya minimal Rp. 31.354,00, Pompa Feeder HFO memiliki tp 3500 jam dengan estimasi biaya minimal Rp. 350.380,00, Pompa Circulating HFO memiliki tp 3500 jam dengan estimasi biaya minimal Rp. 346.017,00, Filter memiliki tp 4800 jam dengan estimasi biaya minimal Rp. 30.619,00, Pompa Injeksi Mesin Utama memiliki tp 2200 jam dengan estimasi biaya minimal Rp. 792.632,00, Katup Injeksi Mesin Utama memiliki tp 1700 jam dengan estimasi biaya minimal Rp. 755.806,00.

Kata Kunci: Kapal Kontainer, RCM, FMECA, Alokasi dan Perencanaan Tugas Pemeliharaan, Biaya Pemeliharaan

PREFACE

Grateful to Allah SWT because of His grace, the author can finish this bachelor thesis with the title "APPLICATION OF RELIABILITY-CENTERED MAINTENANCE (RCM) METHOD FOR FUEL OIL SYSTEM ON MV. KENDARI I PT MERATUS" in order to comply the requirement of obtaining a Bachelor Engineering Degree on Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.

The author realizes that this writing can not be solved without the support of various parties both morally and materially. Therefore, the authors would like to express their gratitude to all those who have helped in the preparation of this bachelor thesis especially to :

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10. All member of Reliability, Availability, Management and Safety (RAMS) Laboratory for the great time and support.
11. Great amounts of friends that can't be mentioned, for their support, help and ideas for this thesis.

The author realizes that this bachelor thesis remains far away from perfect. Therefore, every constructive suggestion and idea from all parties is highly expected by author for this bachelor thesis correction and improvement in the future.

Finally, may Allah SWT bestow His grace, contentment and blessings to all of us. Hopefully, this bachelor thesis can be advantageous for all of us particularly for the readers.

Surabaya, 31 December 2017

Author

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CHAPTER I
INTRODUCTION

1.1. Background

With the fast development of industry and the highly competitive international market, especially the areas of shipping industry needs the company to carry out a production process optimally to fulfill specific objectives. Based on **Table 1.1.** and **Table 1.2.** shown loading and unloading activities at the port of Tanjung Perak. This port has a consistent container flow in Indonesia this can be seen in the data below that every month of loading and unloading activities in the port of Tanjung Perak tends to increase, from these data also proves that shipping company in Indonesia is growing well.

Table 1.1. *Loaded Goods in Foreign and National Ship by Month 2014*

Bulan/Month	Jenis Bongkar Barang/ Unloaded Type			
	Bulk	Break Bulk	General Cargo	Liquid
Februari/February	8,400	263,532	1,433,272	170,821
Maret/March	10,400	96,130	1,922,986	125,330
April/April	60,116	86,896	1,494,986	86,207
Mei/May	16,150	68,029	1,524,382	165,722
Juni/June	11,859	65,428	1,692,389	142,459
Juli/July	6,000	77,708	1,495,374	110,040
Agustus/August	14,600	40,095	1,225,515	126,830
September/ September	11,964	56,247	1,451,129	146,810
Oktober/October	22,162	55,241	1,627,980	103,810
November/November	40,691	53,716	17,317,686	84,115
Desember/December	11,600	52,977	1,266,556	86,672
Jumlah/Total	213,942	915,999	32,452,255	1,348,816
2013	342,009	1,006,841	19,269,824	1,207,414
2012	267,731	1,231,569	17,795,040	1,058,550

Table 1.2. *Unloaded Goods in Foreign and National Ship by Month 2014*

Bulan/Month	Jenis Bongkar Barang/ Unloaded Type			
	Bulk	Break Bulk	General Cargo	Liquid
Januari/January	381,475	358,929	1,226,431	421,867
Februari/February	526,950	350,588	1,298,749	383,003
Maret/March	450,876	372,704	1,322,391	401,774
April/April	613,124	503,586	1,111,303	515,596
Mei/May	507,563	878,648	1,638,726	481,552
Juni/June	302,956	810,317	1,320,877	448,036
Juli/July	474,826	356,617	1,288,630	887,547
Agustus/August	559,320	19,335	1,160,141	319,370
September/ September	543,200	457,026	1,717,389	524,857
Oktober/October	546,180	313,639	1,220,660	380,443
November/November	471,216	484,034	1,218,106	316,115
Desember/December	436,453	377,322	900,969	408,089
Jumlah/Total	5,814,139	5,282,745	15,424,372	5,488,249
2013	6,982,376	6,143,234	16,621,180	4,285,092
2012	6,910,265	4,501,611	16,057,050	4,214,199

That means in this case, shipping companies are forced to undertake a specified transport task with greatest safety, reliability, availability and lowest outlay in order to compete with other shipping companies (Bernhardt, 2009). One factor to consider by shipping company is to maintain operation process of` their ship. Maintenance activities is a requirement since maintenance is a primary service to be performed in complex systems, especially those whose failures can compromise personnel and environmental safety, such as marine ship systems (Deris, 1999).

Maintenance can be performed in two major types: corrective maintenance and preventive maintenance. Corrective maintenance, similar to repair work, is undertaken after a breakdown or when obvious failure has been located. However, corrective maintenance at its best should be utilized only in non-critical areas where capital costs are small, consequences of failure are slight, no safety risks are immediate, and quick failure identification and rapid failure repair are possible. Preventive maintenance is carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or degradation of functioning of an item (Starr, 2000).

One of the most important of marine ship systems is the Fuel Oil System because this system has a very high risk. These systems are composed of pump sets, tanks, controls, filtration systems and other specialty equipment to make up a complete system to meet the needs. Not only consist a complex systems, fuel oil system require a huge amount of money for maintenance process (Meratus, 2017). Thus, there is a need for a strategy that secures a good balance between performance, costs and risks. One of solution by means of using a risk-based maintenance strategy based on Reliability-Centered Maintenance (RCM).

Reliability-centered Maintenance (RCM) analyze the functions and failures of a system and identifies the consequences of these failures to implement preventive measures using a standardized logical resolution procedure (Moubray, 1997). The main objective of Reliability-Centered Maintenance (RCM) is to reduce the maintenance cost, by focusing on the most important functions of the system, and avoiding or removing maintenance actions that are not strictly necessary. If a maintenance program already exists, the result of an Reliability-Centered Maintenance (RCM) analysis will often be to eliminate inefficient preventive maintenance (PM) tasks. Based on **Figure 1.1.** shown case study about maintenance cost comparison of pump with 4 maintenance type (Piotrowski, 2001). From the data below can be concluded if using Reliability-Centered Maintenance (RCM) method we can reduce maintenance cost of a system.

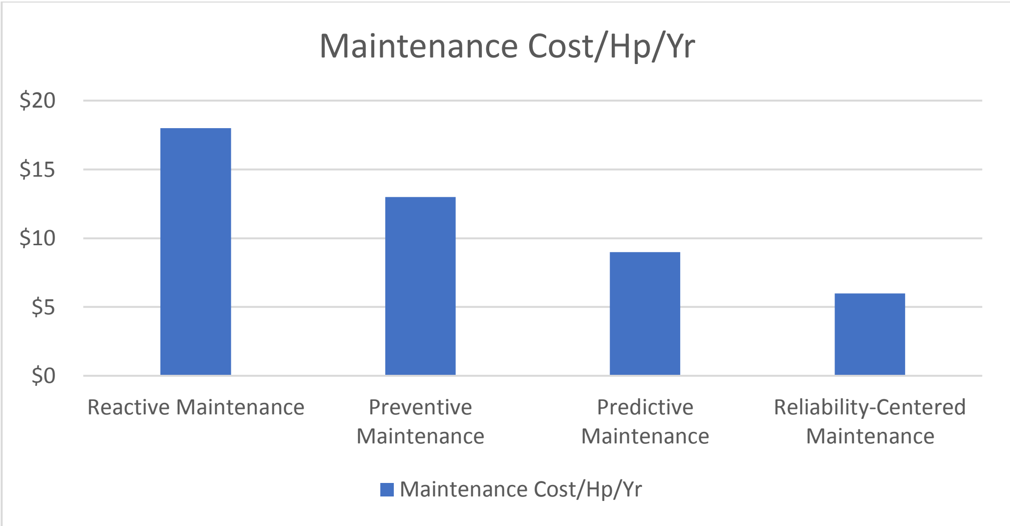

Figure 1.1. *Maintenance Cost Comparison of Pump with 4 Maintenance Type*

According to the SAE JA1011 standard, which describes the minimum criteria that a process must comply with to be called "RCM," a Reliability-Centered Maintenance Process answers the following seven questions :

1. What are the functions and associated desired standards of performance of the asset in its present operating context (functions)?
2. In what ways can it fail to fulfill its functions (functional failures)?
3. What causes each functional failure (failure modes)?
4. What happens when each failure occurs (failure effects)?
5. In what way does each failure matter (failure consequences)?
6. What should be done to predict or prevent each failure (proactive tasks and task intervals)?
7. What should be done if a suitable proactive task cannot be found (default actions)?

An effective and efficient maintenance management will improve the performance and optimize the desired lifetime of a system. In this research, writer shall apply Reliability-Centered Maintenance (RCM) process with Failure Mode, Effects and Criticality Analysis (FMECA) from ABS Rules to fuel oil system on MV. Kendari I PT Meratus Line. Reliability-Centered Maintenance (RCM) process of ABS rules can be used to determine the failure rate and precise maintenance planning from each component. Whereas the result expected can be used to plan the maintenance program without disturb ship operational schedule. Reliability-Centered Maintenance (RCM) process can determine the prioritize scale of maintenance of each component, especially component with vital function.

1.2. Research Problems

Based on background mentioned above, it can be concluded some problems of this final project are :

a. What components are causing the failure and their impacts of Fuel Oil System on MV. Kendari I PT Meratus Line?
b. What is the most effective maintenance type that can be done to anticipate if the failure occurred of Fuel Oil System on MV. Kendari I PT Meratus Line?
c. What is the maintenance costs of Fuel Oil System on MV. Kendari I PT Meratus Line will be reduced if using Reliability-Centered Maintenance (RCM) method ?

1.3. Research Limitations

This final project can be focused and organized, with limitations on problem which are :

a. In this research using Reliability-Centered Maintenance (RCM) process as applied in the Guide for Survey Based on Reliability-Centered Maintenance (RCM Guide) by the American Bureau of Shipping (ABS).
b. Research object is Fuel Oil System on MV. Kendari I PT Meratus Line.
c. The failure data of components is taken from planned maintenance system of MV. Kendari I PT Meratus Line within 7 years (during 2011-2017)
d. The Reliability-Centered Maintenance (RCM) analysis of Fuel Oil System on MV. Kendari I PT Meratus Line ignores the effects of human error and natural influences

1.4. Research Objectives

Based on problems mention above, the objectives of this final project are :

a. To identify what components are causing the failure and their impacts of Fuel Oil System on MV. Kendari I PT Meratus Line.
b. To identify the most effective maintenance type that can be done to anticipate if the failure occurred of Fuel Oil System on MV. Kendari I PT Meratus Line.
c. To analyze maintenance costs of Fuel Oil System on MV. Kendari I PT Meratus Line if using Reliability-Centered Maintenance (RCM) method.

1.5. Research Benefits

This final project is expected to give benefits for the various kind of parties. The benefits that can be obtained are :

a. Provides information about the components are causing the failure and their impacts of Fuel Oil System on MV. Kendari I PT Meratus Line.
b. Provides information about the most effective maintenance type that can be done to anticipate if the failure occurred of Fuel Oil System on MV. Kendari I PT Meratus Line.
c. Provides information about maintenance costs of Fuel Oil System on MV. Kendari I PT Meratus Line if using Reliability-Centered Maintenance (RCM) method.

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CHAPTER II
LITERATURE STUDY

2.1. Fuel Oil System as the Object of Research

The fuel oil system is extremely important system on a ship which is designed to supply clean fuel oil to main engine, diesel generators and emergency diesel generator. The reliability and the performance of the system are directly responsible for accommodate effective voyage of the ship. On the other hand, it is not easy to keep the system performance always stable, high and reliable because the fuel oil system is a complex system and tendency to malfunction.

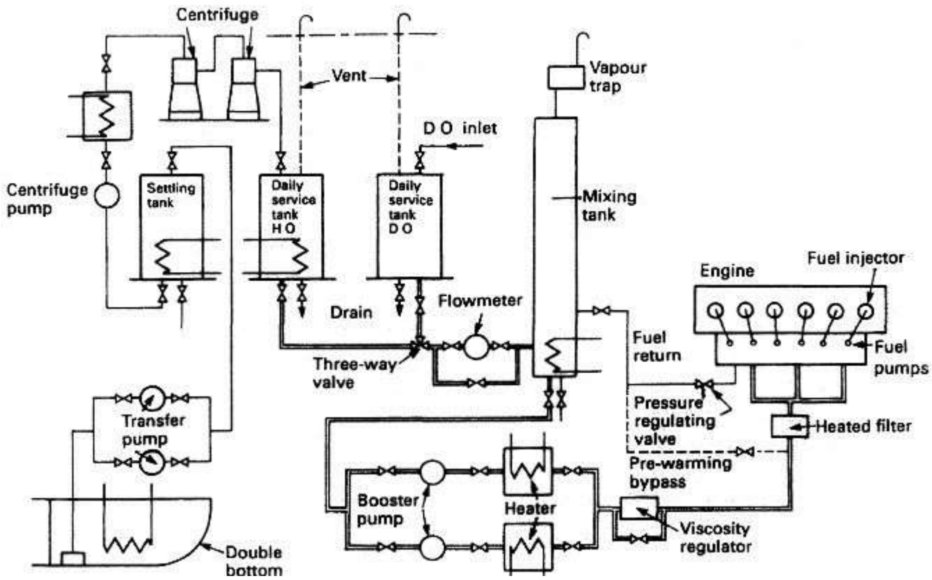

Figure 2.1. *Fuel Oil System Diagram*

The fuel oil system is comprised of storage tanks, service tanks, transfer pump, heaters, purifiers, manifolds, valves, strainers, filters, flow meters and piping which are shown in **Figure 2.1.**.The fuel oil storage and service tanks are equipped with level indicators and level transmitters. The heavy oil service tank uses a suction heater to adjust oil viscosity while storage tank uses a whole tank heating system to maintain the oil above the pour point temperature. The pumps are used to transfer fuel oil to the whole system. The fuel oil purifiers are utilized for separate other liquids and the oils and also removal of solids. Strainers are responsible for removing hard solid particulate matter that may damage rotating equipment. Fuel oil is filtered to extract particulate matter and to remove water. Filters which are designed to remove water from fuel oil are known as duplex filters. The fuel known as coalescing filters. The fuel oil pipeline flow meter is used to measure fuel oil quantities for accounting purposes.

In addition to complexity of the systems, fuel oil system is also a system that requires a large maintenance costs. Based on **Figure 2.2.** shown maintenance costs of the fuel oil system on MV Kendari I PT Meratus Line.

NOZZLE ELEMENT	MAK	M453C	1.0-3	1.2261A
NOZZLE ELEMENT	MAK	M453C	1.0-3	1.2261A
NOZZLE HOLDER	MAK	M453C	10.0-2	1.2267 N
NOZZLE HOLDER	MAK	M453C	10.0-2	1.2267 N
PARALLEL PIN	MAK	M453C	10.0-4	1.2267 N
NOZZLE NUT	MAK	M453C	10.0-5	1.2267 N
PRESSURE PIN	MAK	M453C	10.0-6	1.2267 N
NOZZLE SPRING	MAK	M453C	10.0-8	1.2267 N
O-RING	MAK	M453C	10.0-11	1.2267 N
O-RING	MAK	M453C	10.0-12	1.2267 N
JOINT RING	MAK	M453C	00-1	1.2267 N
NOZZLE SPRING	MAK	M453C	10.0-8	1.2267 N

Figure 2.2. *Maintenance costs for FO System on MV. Kendari I*

2.2. Implementation Maintenance Management

Today's increasingly competitive industry, competition in effectiveness and efficiency is increasing it demands an increase in the availability (level of availability) of equipment to support the production process so that required maintenance management system. Maintenance management activities are absolutely necessary with the best activities that are activities oriented to guarantee the reliability of an equipment.

PT Meratus Line is one of Indonesian shipping company that provides point-to-point transportation solutions. Operating a network of liner services connecting major ports in Indonesia and supported by many offices that spread throughout Indonesia. Because the services offered by PT Meratus Line is the delivery of goods between ports so that container vessel is one of the company's main assets in supporting the productivity of the company. In the event of damage in container vessel operations, it will lead to cessation of productivity or business fields that exist in the company and a direct impact on the company's economy.

Maintenance Management is a regular and systematic approach to planning, organizing, monitoring and evaluating maintenance activities and costs. A good maintenance management system combined with acceptable knowledge and high quality staff for maintenance is able to prevent health and safety issues and environmental damage; produces life assets with fewer interuptions and results in lower operating costs and higher quality of life. Maintenance management is a system consisting of several elements in the form of facilities, replacement of components or spare parts (material), cost of maintenance (money), planning of maintenance activities (method), and executor of maintenance (man). These elements are interrelated and interact in maintenance activities in the industry (Ansori, 2013).

The purpose of maintenance activities is supporting the business activities that the company desires, in general the maintenance strives to keep the facilities or facilities always in a ready condition for the production process in accordance with the plan, and not damaged during the facility or equipment used in the production process.

The main objectives of maintenance activities of equipment or machinery are (Assauri, 1987) :

1. Production capability can fulfill requirement according to production plan
2. Maintain equipment quality at the right level to meet what is needed by the product itself and uninterrupted production activities
3. To help reduce unnecessary usage and deviations of the capital and keep the capital that being invested in the company during the time specified in accordance with the company's policy on the investment
4. To achieve the lowest level of maintenance cost possible, by carrying out maintenance activities effectively and efficiently overall
5. Ensure the safety of equipment and the operators
6. Hold close cooperation with other major functions of a company that is the level of profit or return of investment as possible and the lowest total cost.

2.3. Reliability

Reliability is defined to be the probability that a component or system will perform a required function for a some period of time when used in user needed operating conditions (Ebeling, 1997). whereas according to (Blancard, 1994) reliability is the probability that a unit will provide a satisfactory ability for a particular purpose within a certain period of time when under certain environmental conditions. Related to the reliability of a system there are things to note that is failure, where the system can not work properly. Reliability can also be defined as the probability of an item in order to perform a predetermined function, under certain operating and environmental conditions for a predetermined period of time (Priyanta, 2000).

In general there are two methods developed to evaluate the reliability of a system, namely :

1. Quantitative Method

Quantitative method is a method of analysis in the form of mathematical calculations performed through approach / numerical distribution. This method is done through the acquisition of secondary data in the form of data maintenance (equipment record) to the time of failure (TTF) where Time to Failure is defined as the time passed by the component when it started to operate until failure and time of repair (TTR) required by the component to work again. TTF and TTR components follow some known distribution failures such as normal distribution, lognormal, exponential, weibull.

2. Qualitative Method

Qualitative method is a method of quality analysis through the practical perspective of a problem. Qualitative method is best used by experienced practioner. To design the qualitative method by using the pattern of getting the data with the leather technique also. Examples are modes and failure effects, such as Failure Mode and Effects Analysis (FMEA), Failure Mode, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA) and Reliability-Centered Maintenance (RCM). Qualitative analysis is used to analyze the system to look for the most effective type of activity in terms of failure.

2.4. Reliability Function

Reliability function is a mathematical function that states the relationship of reliability with time. The value of reliability function is probability value, then the value of function reliability (R) is $0 \leq R \geq 1$ (Ebeling, 1997). The reliability function is denoted as R (t) of the system if it is used for t time units. Probability system works well during usage [0, t]. Parameters to be measured in data processing is the failure rate of component. These parameters are random variables that can be defined continuously. The concept of time in reliability is TTF (time to failure). TTF as the time the component passes when it starts operating until it fails.

Calculation of reliability values in general, using the following equation (Ebeling, 1997).

$$R(t = 1 - F(t) = \int_0^\infty f(t)$$

Where :

F (t) : Cumulative Distribution Function (CDF)

R (t) : Reliability Function

f (t) : Probability Density Function (PDF)

2.5. Availability

Availability is defined as the probability that a component or system is performing its required function at a given point in time when used under stated operating conditions (Ebeling, 1997). Availability may also be interpreted as the probability of being able to find a system (with various combinations of its reliability aspects, maintainability and maintenance support) to perform the required functions over a given period of time (Priyanta, 2000). According to **Figure 2.3.** availability is a function of an operating time cycle (reliability) and down time (maintainability).

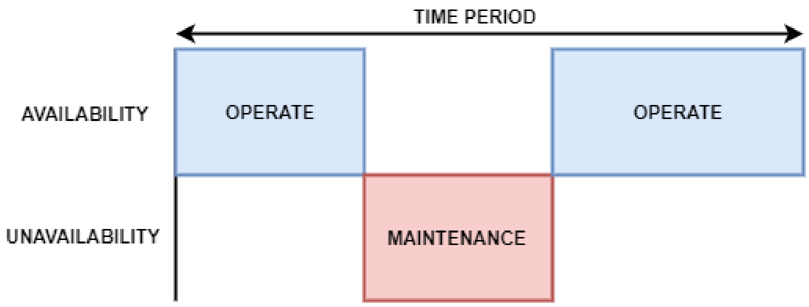

Figure 2.3. *Availability Illustration (Priyanta, 2000)*

The changing availability over time can be calculated using the equation below (Ebeling, 1997).

$$A(t) = \left[\left(\frac{\mu}{\lambda + \mu}\right) + \left(\left(\frac{\lambda}{\lambda + \mu}\right) exp(-(\lambda + \mu)t)\right)\right]$$

Where :

λ : Failure rate of time between failures

μ : 1 / MTTR

2.6. Maintainability

Maintainability is defined to be the probability that a failed component or system will be restored or repaired to a specified condition within a period of time when maintenance is performed in accordance with prescribed procedure (Ebeling, 1997). While (Corder, 1996) states that maintenance is "a combination of actions taken to keep an item in, or to fix it until, an acceptable condition". Maintainability may also be interpreted as the ability of an item under certain conditions of use, to be treated, or returned to its original state where it can perform the necessary functions, if the maintenance is carried out under certain conditions and by the use of prescribed procedures and resources (Priyanta, 2000).

Maintainability has different formulas on each data distribution (Ebeling, 1997). The maintainability value can be written like the following equation:

1. Normal Distribution

$$M(t) = \varphi\left(\frac{t-\mu}{\sigma}\right)$$

Where :

t : Time (variable)

μ : Average

σ : Standard deviation

2. Lognormal Distribution

$$M(t) = \frac{1}{\sigma t\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{In(t-\mu)}{\sigma}\right)^2\right]$$

Where :

t : Time (variable)

μ : Average

σ : Standard deviation

3. Weibull Distribution
   - Two parameter :

$$M(t) = 1 - exp\left[-\frac{t}{\eta}^{\beta}\right]$$

- Three parameter :

$$M(t) = 1 - exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right]$$

Where :

t : Time (variable)

β : Shape parameter

η : Scale parameter

γ : Location parameter

4. Exponential Distribution

$$M(t) = 1 - e^{-\frac{t}{MTTR}}$$

Where :

t : Time (variabel)

MTTR : Mean Time To Repair

For the mean time to repair (MTTR) in some distributions can use the equation as follows :

1. Normal Distribution

$$MTTR = \mu$$

2. Lognormal Distribution

$$MTTR = exp\left(\mu + \frac{\sigma^2}{2}\right)$$

3. Weibull Distribution
   - Two parameter :

$$MTTR = \eta\Gamma\left(1 + \frac{1}{\beta}\right)$$

- Three parameter :

$$MTTR = t0 + \eta\Gamma\left(1 + \frac{1}{\beta}\right)$$

4. Exponential Distribution

$$MTTR = \gamma + \frac{1}{\lambda}$$

Where :

t : Time (variabel)

MTTR : Mean time to repair

2.7. Failure Rate

Failure rate is the number of failures per unit of time. The failure rate is expressed as the ratio between the number of failures that occur within a certain time interval with the total operating time of a component or system. The failure rate can be calculated with equations below (Ebeling, 1997).

$$\lambda = \frac{f}{T}$$

$$\lambda = \frac{f(t)}{R(t)}$$

Where :

f : Number of failures during operation period

T : Total operation time

λ(t) : Failure rate

Here is an explanation of the distribution of failure rates that have four types of distribution.

2.7.1. Normal Distribution

A normal distribution, also called a gaussian distribution, is the most commonly used distribution to explain the spread of data. Probability Density Function (PDF) of the normal distribution is symmetrical to the mean. Dispersion to mean value of normal distribution is measured by standard deviation value (σ). In other words the normal distribution parameter is the mean and standard deviation (σ). Probability Density Function (PDF) of normal distribution can be expressed by the equation below (Ebeling, 1997).

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^2\right]$$

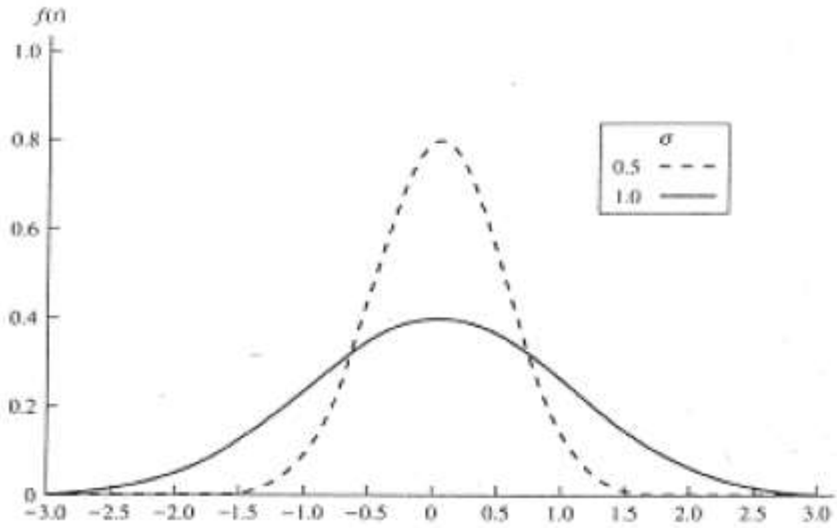

Figure 2.4. *Normal Distribution*

If the distribution of a system follows a normal distribution, then :

1. The normal distribution reliability function is :

$$R(t) = 1 - \Phi\left(\frac{t-\mu}{\sigma}\right)$$

2. The normal distribution failure rate is :

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{f(t)}{1 - \Phi\left(\frac{t-\mu}{\sigma}\right)}$$

3. The normal distribution mean time to failure is :

$$MTTF = \mu$$

Where :

t : Time (variable)

μ : Average

σ : Standard deviation

2.7.2. Lognormal Distribution

When the random variable T (failure time) has a lognormal distribution, the logarithm T has a normal distribution. The function for the lognormal distribution is shown in equation below (Ebeling, 1997).

$$f(t) = \frac{1}{\sigma t\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{Int-\mu}{\sigma}\right)^2\right]$$

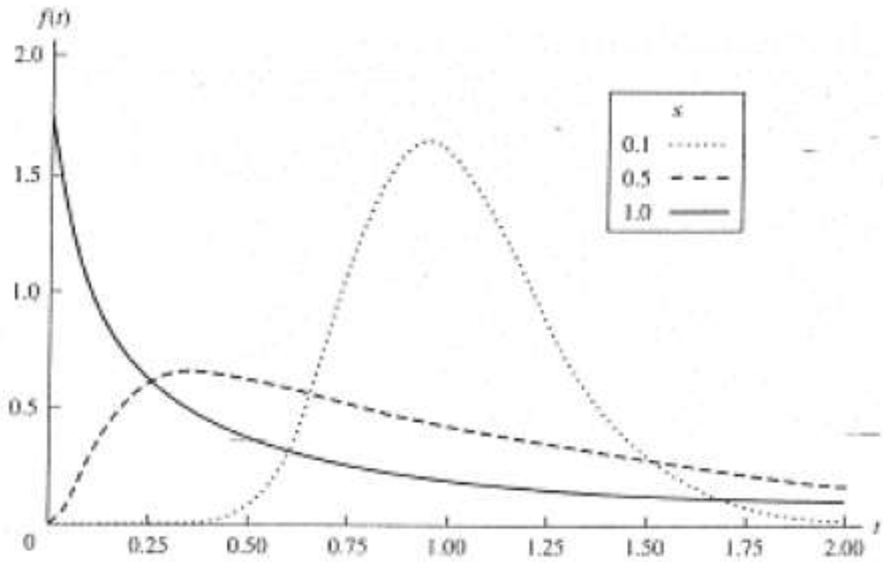

Figure 2.5. *Lognormal Distribution*

Characteristics of lognormal distribution has two parameters, including location parameter (μ) and scale parameter (σ), equal to standard deviation. If the distribution of a system follows a lognormal distribution, then :

1. The lognormal distribution reliability function is :

$$R(t) = 1 - \Phi\left(\frac{t-\mu}{\sigma}\right)$$

2. The lognormal distribution failure rate is :

$$\lambda(t) = \frac{f(t)}{R(t)} = \frac{f(t)}{1 - \Phi\left(\frac{t-\mu}{\sigma}\right)}$$

3. The lognormal distribution mean time to failure is :

$$MTTF = \mu$$

Where :

t : Time (variable)

μ : Average

σ : Standard deviation

2.7.3. Weibull Distribution

In addition to the normal distribution, weibull distributions are also most commonly used in Reliability. The model bathub curve is the basis for performing a reliability calculation of a component or system. The addition of parameters in the weibull distribution can present the Probability Density Function (PDF), so that this distribution can be used for wide data variations. Here is a function of the weibull distribution parameter :

1. η, as a scale parameter, η> 0, is called characteristic life
2. β, as a form parameter, β> 0, describes the shape of the PDF (Probability Density Function PDF).
3. γ, as the location parameter, ie representing failure-free or the beginning of the period from the use of the tool. If γ = 0 then the distribution will change into two parameters.

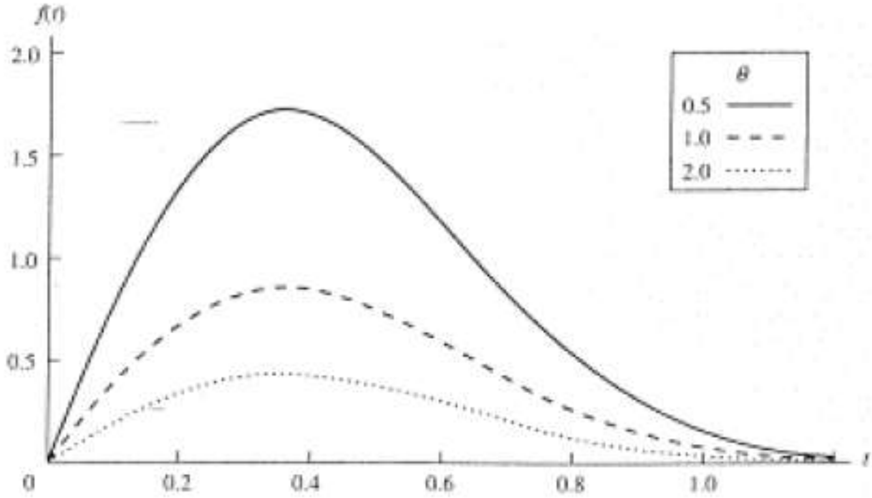

Figure 2.6. *Weibull Distribution*

The characteristic of weibull distribution has several parameters on its distribution, ie two parameters (η, β) and three parameters (η, β, γ) :

- Distribution of two parameters

1. The PDF of the weibull distribution is :

$$f(t) = \frac{\beta}{\eta}\left[\left(\frac{t}{\eta}\right)^{\beta-1}\right] exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right]$$

2. The weibull distribution reliability function is :

$$R(t) = exp\left\{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right\}$$

3. The weibull distribution failure rate is :

$$\lambda(t) = \frac{\beta}{\eta}\left[\frac{t}{\eta}\right]^{\beta-1}$$

4. The weibull distribution mean time to failure is :

$$MTTF = \eta\Gamma\left(1+\frac{1}{\beta}\right)$$

- Distribution of three parameters

1. The PDF of the weibull distribution is :

$$f(t) = \frac{\beta}{\eta}\left[\left(\frac{t - t0}{\eta}\right)^{\beta-1}\right] exp\left[-\left(\frac{t - t0}{\eta}\right)^{\beta}\right]$$

2. The weibull distribution reliability function is :

$$R(t) = exp\left\{-\left(\frac{t - t0}{\eta}\right)^{\beta}\right\}$$

3. The weibull distribution failure rate is :

$$\lambda(t) = \frac{\beta}{\eta}\left[\frac{t - t0}{\eta}\right]^{\beta-1}$$

4. The weibull distribution mean time to failure is :

$$MTTF = t0 + \eta\Gamma\left(1 + \frac{1}{\beta}\right)$$

Where :

t : Time (variable)

β : Shape parameter

η : Scale parameter

γ : Location parameter

2.7.4. Exponential Distribution

Probability Density Function (PDF) The exponential distribution is shown in the following equation (Ebeling, 1997).

$$f(t) = \lambda e^{-\lambda(t-\gamma)}\, , t > 0\, , \lambda > 0\, , t \geq \gamma$$

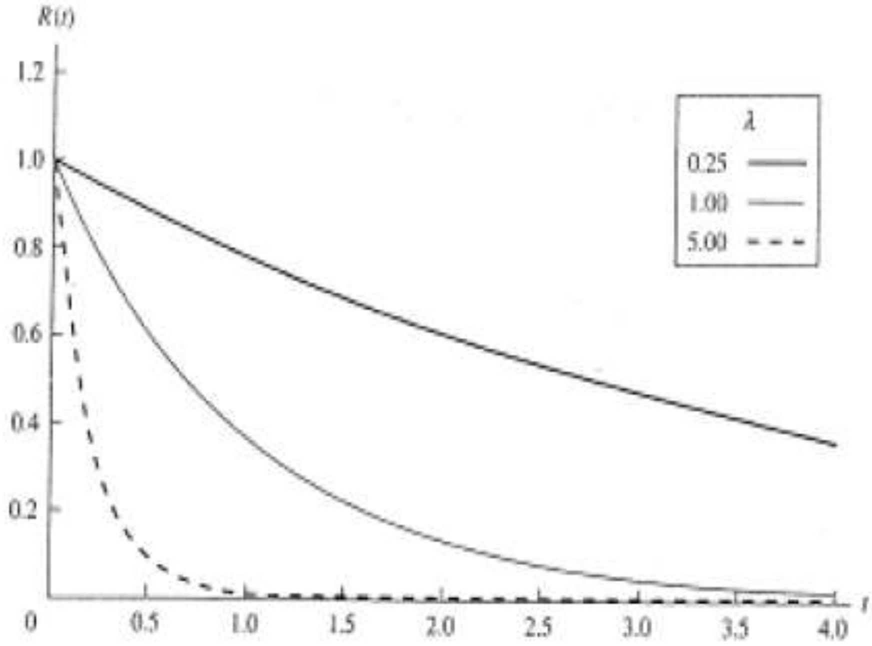

Figure 2.7. *Exponential Distribution*

If the distribution of a system follows a exponential distribution, then :

1. The exponential distribution reliability function is :

$$R(t) = e^{-\lambda(t\gamma)}$$

2. The exponential distribution failure rate is :

$$\lambda(t) = \lambda$$

3. The exponential distribution mean time to failure is :

$$MTTF = \gamma + \frac{1}{\lambda}$$

Where :

t : Time (variable)

MTTR : Mean time to repair

2.8. Method for Distribution Determination

According to software Weibull++ Version 6, There are basically two methods of parameter estimation in spread to be use in reliability analysis: maximum likelihood estimation and regression. And regression are also had two forms: regression on X and regression on Y. Regression generally works best with data sets with smaller sample sizes (if the sample size more than 30, these differences become less important) that contain only complete data (i.e., data in which all of the units under consideration have been run or tested to failure). This failure-only data is best analyzed using rank regression on X, as it is more prefer to the user to regress in the direction of uncertainty. If a reliability test is repeated with the same number of units operated to failure in each experiment, the failure times would change from test to test, but the rank values would remain the same, since they are based solely on sample size and order number. Therefore, the uncertainty is on the failure time values, which is on the x-axis, so regression in the X direction is the most appropriate. It has also been shown that for smaller sample sizes, rank regression on X tends to produce more accurate results than rank regression on Y.

Rank regression on Y is best used with data other than time-to-failure data, such as free-form data. An example of this would be warranty data that have unreliability estimates for each month of a warranty period. These would be plotted on a probability plot much as regular failure time data. Since we know the time values in question, and the unreliability values are estimates, the uncertainty is in the Y direction, and regression on Y would be more appropriate.

For data sets that contain a number of random suspensions, maximum likelihood estimation methods usually provide better results. This is because this method better incorporates the time-to-suspension points into the parameter estimates.

2.9. Types of Maintenance

Maintenance actions can be planned maintenance and unplanned maintenance. However, there are maintenance actions that need to be done immediately in case of serious incidents where if not done maintenance action will cause serious consequences such as inhibition of production process, equipment damage, and safety reason which is called emergency maintenance (Corder, 1996).

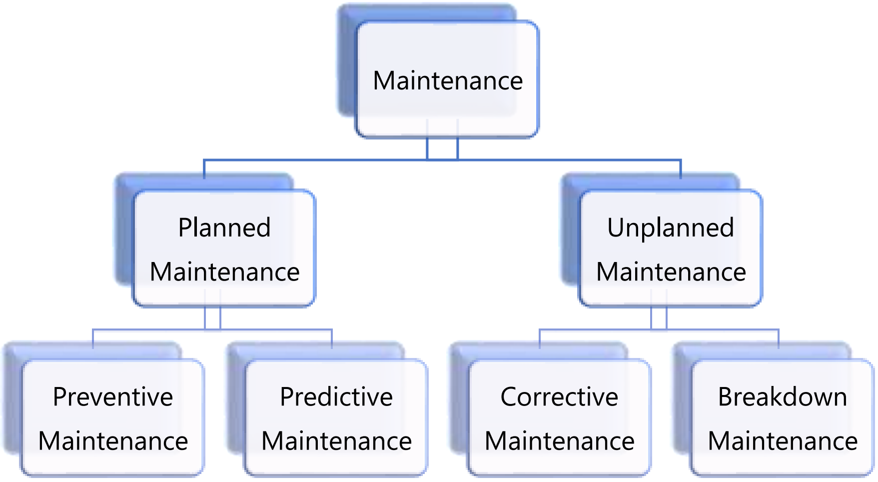

Figure 2.8. *Types of Maintenance (Corder, 1996)*

Based on **Figure 2.8.** an explanation of the type of maintenance (Corder, 1996) is as follows :

1. Preventive Maintenance

It is daily maintenance (cleaning, inspection, oiling, and re-tightening). Design to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis to measure deterioration. It is further divided into periodic maintenance and predictive maintenance. At **Table 2.1.** showing the advantage and disadvantage of preventive maintenance.

Table 2.1. *Advantages and Disadvantages of Preventive Maintenance*[5]

Advantages	Disadvantages
Over all very cost effective	Catasthropic failure still a risk
Flexibility can allow for adjustment of schedule to accommodate other work	Labour intensive
Increased equipment life	Performance of maintenance based on schedule not required
Saved energy cost resulting from equipment running from pick efficiency	Risk of damage when conducting unneeded maintenance
Reduced equipment or process failure	Saving not readily visible without a base line
Over all saving between 12% to 18%	

2. Predictive Maintenance

This is a method in which equipment lifetime is predicted based on inspection or diagnosis. In order to use equipment or part until their best potential. Predictive maintenance is condition based maintenance. It manages the values by measuring and analysing data about deterioration. At **Table 2.2.** showing the advantage and disadvantage of predictive maintenance.

Table 2.2. *Advantages and Disadvantages of Predictive Maintenance*[6]

Advantages	Disadvantages
Increased component operational life/availability	Increased investment of diagnostic equipment
Allows for pre-emptive corrective action	Increased staff training for analysing data
Decreased part and labour cost	Saving not readily visible without a baseline/history
Improved safety and environment	
Energy savings	
Over all saving between 8% to 12% over preventive maintenance	

3. Corrective Maintenance

It improves equipment and its components so that preventive maintenance can be carried out reliably. Every equipment with design weakness must be redesigned to improve reliability or improving maintainability At **Table 2.3.** showing the advantage and disadvantage of corrective maintenance.

Table 2.3. *Advantages and Disadvantages of Corrective Maintenance*[7]

Advantages	Disadvantages
Lower short-term costs	Increased long-term costs due to unplanned equipment downtime
Requires less staff since less work is being done	Possible secondary equipment or process damage
	Prone to neglect of assets

4. Breakdown Maintenance

It means that people waits until equipment fails and repair it. Such a thing could be used when the equipment failure does not significantly affect the operation or production or generate any significant loss other than repair cost. At **Table 2.4.** showing the advantage and disadvantage of breakdown maintenance.

Table 2.4. *Advantages and Disadvantages of Breakdown Maintenance[8]*

Advantages	Disadvantages
Lower start up cost	Unpredictability
Limited personnel requirement	Equipment not maximized
Reduced maintenance costs	Indirect costs
Potentially increased margins	

2.10. Evolution of Maintenance

According to Moubray (Moubray, 1997), since the 1930's, the evolution of maintenance can be traced through three generations :

1. The First Generation

It covers the period before World War II happend. In those days industry was not very highly depend of machinery, so downtime did not matter much. This meant that the prevention of equipment failure was not a very high priority in the minds of most managers. At the same time, most equipment was simple and much of it was over-designed. This made it reliable and easy to repair. As a result, there was no need for systematic maintenance of any sort beyond simple cleaning, servicing and lubrication routines. The need for skills was also lower than it is today.

2. The Second Generation

As this dependence to machinery grew, downtime came into sharper focus. This led to the idea that equipment failures could happened anytime and should be prevented, which led in turn to the concept of preventive maintenance. In the 1960's, this consisted mainly of equipment overhauls done at fixed intervals. The cost of maintenance also started to rise sharply relative to other operating costs. This led to the growth of maintenance planning and control systems. These have helped greatly to bring maintenance under control, and are now an established part of the practice of maintenance. Finally, the amount of capital tied up in fixed assets together with a sharp increase in the cost of that capital led people to start seeking ways in which they could maximise the life of the assets.

3. The Third Generation

Since the mid-seventies, the process of change in industry has gathered even greater momentum. The changes can be classified under the headings of new expectations, new research and new techniques.

- New Expectations

Downtime has always affected the productive capability of physical assets by reducing output, increasing operating costs and interfering with customer service. By the 1960's and 1970's, this was already a major concern in the mining, manufacturing and transport sectors. In manufacturing, the effects of downtime are being aggravated by the worldwide move towards just-in-time systems, where reduced stocks of work-in-progress mean that quite small breakdowns are now much more likely to stop a whole plant.

More and more failures have serious safety or environmental consequences, at a time when standards in these areas are rising rapidly. In some parts of the world, the point is approaching where organizations either conform to society's safety and environmental expectations, or they cease to operate. **Figure 2.9.** shows how expectations of maintenance have evolved.

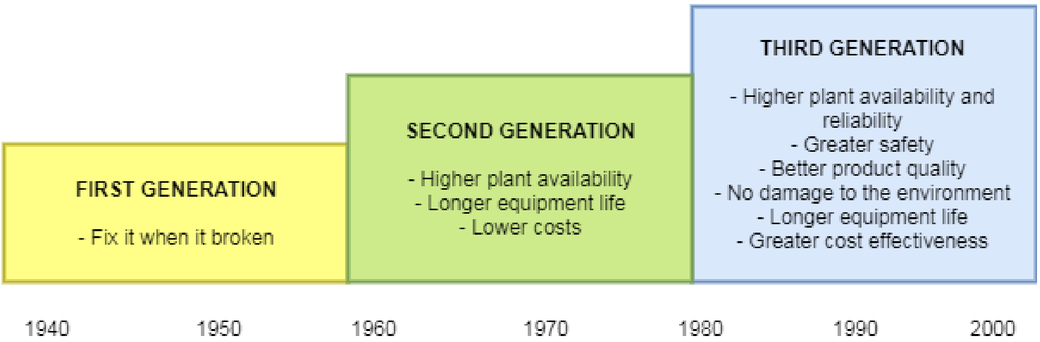

Figure 2.9. *New Expectations (Moubray, 1997)*

- New Research

Quite apart from greater expectations, new research is changing many of our most basic beliefs about age and failure. In particular, it is apparent that there is less and less connection between the operating age of most assets and how likely they are to fail.

Figure 2.10. shows how the earliest view of failure was simply that as things got older, they were more likely to fail. A growing awareness of 'infant mortality' led to widespread Second Generation belief in the "bathtub" curve. However, Third Generation research has revealed that not one or two but six failure patterns actually occur in practice.

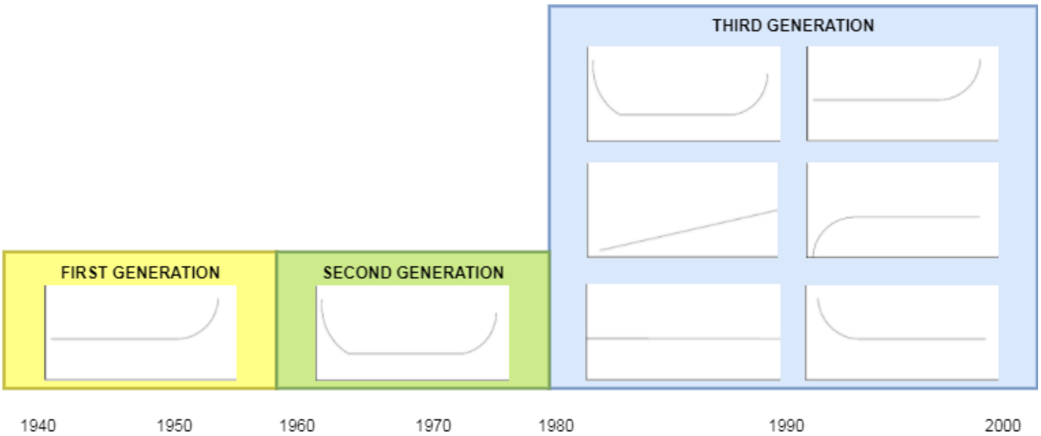

Figure 2.10. *New Research (Moubray, 1997)*

- New Techniques

There has been explosive growth in new maintenance concepts and techniques. Figure 2.11. shows how the classical emphasis on overhauls and administrative systems has grown to include many new developments in a number of different fields.

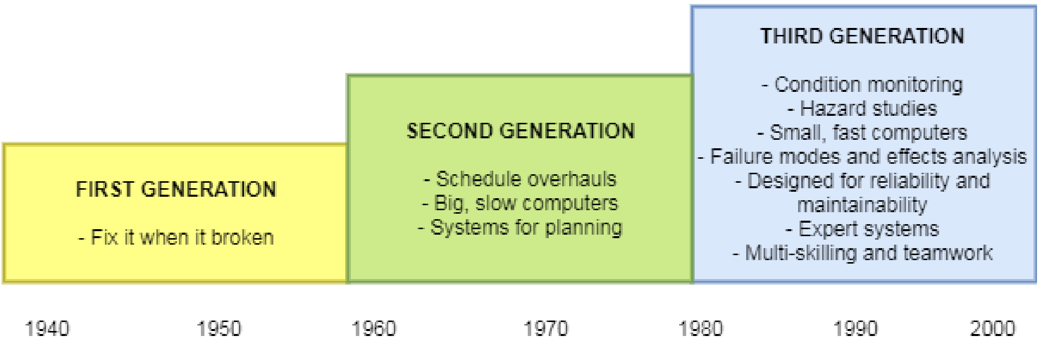

Figure 2.11. *New Techniques (Moubray, 1997)*

From the explanation of new expectations, new research and new techniques we can conclude that into the new developments :

- Decision support tools, such as hazard studies, failure modes and effects analyses and expert systems
- New maintenance techniques, such as condition monitoring
- Designing equipment with a much greater emphasis on reliability and maintainability
- A major shift in organizational thinking towards participation, team-working and flexibility.

2.11. Reliability-Centered Maintenance

2.11.1. Definition of Reliability-Centered Maintenance

According to (Jardine, 2001) Reliability-Centered Maintenance (RCM) is a logical engineering process for determining maintenance tasks that make sure a reliability system design with specific operating conditions in a particular operating environment.

The greatest focus point on Reliability-Centered Maintenance (RCM) is to realize that the consequences or risks of failure are far more important than the characteristics of the technique itself. In fact proactive maintenance not only avoids failure but is more likely to avoid risk or reduce failure (Moubray, 1997).

RCM is a technique that used to developing Preventive maintenance (Ben-Daya, 2000). This is based on the principle that the reliability of the equipment and the structure of performance to be achieved is a function of the planning and quality of effective preventive maintenance establishment. The plan also includes predicted and recommended replacement parts (Irawan, 1998).

2.11.2. History of Reliability-Ceentered Maintenance

Reliability-centered Maintenance (RCM) originated in the Airline ndustry in the 1960s. By the late 1950's, the cost of Maintenance activities in this industry had become high enough to warrant a special investigation into the effectiveness of those activities. Accordingly, in 1960, a task force was formed consisting of representatives of both the airlines and the FAA to investigate the capabilities of preventive maintenance. The founding of this task force consecunce led to the development of a series of guidelines for airlines and aircraft manufacturers to use, when establishing maintenance schedules for their aircraft.

This led to the 747 Maintenance Steering Group (MSG) document MSG-1; Handbook: Maintenance Evaluation and Program Development from the Air Transport Association in 1968. MSG-1 was used to develop the maintenance program for the Boeing 747 aircraft, the first maintenance program to apply Reliability-centered Maintenance (RCM) concepts. MSG-2, the next revision, was used to develop the maintenance programs for the Lockheed L-1011 and the Douglas DC 10. The success of this program is demonstrated by comparing maintenance requirements of a DC-8 aircraft, maintained using standard maintenance techniques, and the DC-10 aircraft, maintained using MSG-2 guidelines. The DC-8 aircraft has 339 items that require an overhaul, verses only seven items on a DC-10. Using another example, the original Boeing 74

7 required 66,000 labor hours on major structural inspections before a major heavy inspection at 20,000 operating hours. In comparison, the DC-8 a smaller

and less sophisticated aircraft using standard maintenance programs of the day required more than 4 million labor hours before reaching 20,000 operating hours (Jones, 1995).

The MSG suggested a system-based approach derived from the curves that used a logic tree for decision making. In 1975 the US Department of Defence directed the MSG concept to be labelled "reliability-centred maintenance" and to be applied to all major military systems (Smith, 1993). Reliability-centered Maintenance (RCM) has gained considerable recognition in the armed navies. Besides the Nowlan and Heap report, which was a product of the US Navy, the UK Ministry of Defence has published Defence Standard 02- 45 (NES 45) that is based on RCM-Il. The US Naval Aviation also uses Reliability-centered Maintenance (RCM). However, the approaches seem too resource demanding and may not be suitable for an unorganise industry like maritime without modification.

2.11.3. Scope of Reliability-Ceentered Maintenance

There are four major components in reliability-centered maintenance (RCM) described in the Figure 2.12. below, namely reactive maintenance, preventive maintenance, predictive testing and inspection, and proactive maintenance (F.S. Nowlan, 1978).

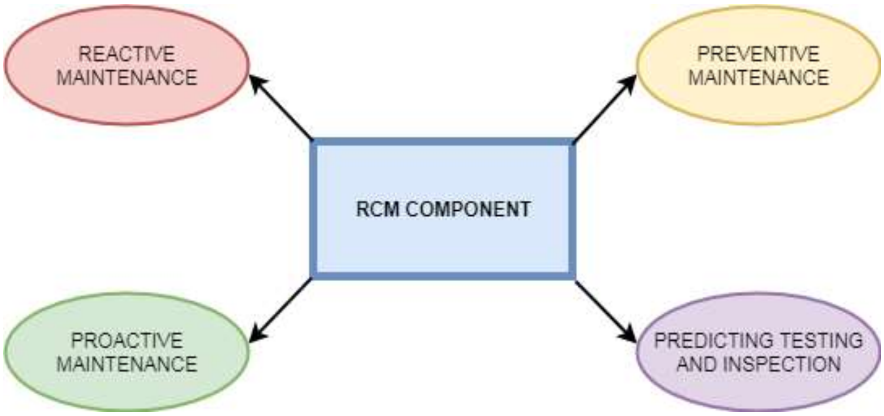

Figure 2.12. *RCM Components (Nowlan, 1978)*

1. Reactive Maintenance

Reactive Maintenance this type of maintenace is also known as breakdown, maintain if damage occurs, run-to-failure or repair maintenance. When using a maintenance approach, equipment repair, maintenance, or replacement only when the item fails the function. In this type of maintenace it is assumed to be equal to the chance of failure on various parts, components or systems.

In general, reactive maintenance is done to find out how much item survivability of each component because this type of maintenance opportunity of failure equal to maintenance or repair performed on each component and system. This is done to determine the ratio of the cost of the asset owner when doing repair during breakdown with maintenance cost based on RCM analysis.

2. Preventive Maintenance

Preventive maintenance (PM) is the most important part of the maintenance activities. Preventive maintenance can be interpreted as a maintenance measure to keep the system/sub-assembly in order to keep operating in accordance with its function by preparing systematic inspection, detection and correction on minor damage to prevent the occurrence of greater damage. Some of the main objectives of preventive maintenance are to increase the productive life of components, reduce the breakdown of critical components, to obtain the planning and scheduling of the required maintenance.

In order to develop an effective preventive maintenance program, several historical features of motorcycle maintenance, manufacturing recommendations, service manuals, identification of all components, test equipment and tools, damage information based on problems, causes or actions taken. Preventive maintenance (PM) is the most important part of the maintenance activities. Preventive maintenance can be interpreted as a maintenance measure to keep the system / sub-assembly in order to keep operating in accordance with its function by preparing systematic inspection, detection and correction on minor damage to prevent the occurrence of greater damage. Some of the main objectives of preventive maintenance are to increase the productive life of the components, reduce the downtime of critical components, to obtain the planning of the required maintenance.

To develop an effective preventive maintenance program, several things are needed, including historical records of a system maintenance, manufacturing recommendations, service manuals, identification of all components, test equipment and tools, damage information based on problems, causes or actions taken.

3. Proactive Maintenance

This type of maintenance helps improve maintenance through actions such as better in every way such as design, workmanship, installation, scheduling, and maintenance procedures. The characteristics of proactive maintenance include implementing an ongoing development process, using feedback and communication to ensure that design changes / procedures made by the designer / management are effective, ensuring that no effect on maintenance takes place in the overall isolation, with the ultimate goal of optimizing and combining methods maintenance with technology in each application

These include root-cause analysis and predictive analysis to improve maintenance effectiveness, influence periodic evaluation of technical content and distance performance between maintenance tasks with one another, improve functionality by supporting maintenance in maintenance program planning, and using a view of life-cycle based maintenance and support functions.

4. Predicting Testing and Inspection

Age-reliability characteristic or periodic reliability on each component will certainly be different. In general this information is not included by the manufacturer so to determine the preventive maintenance schedule needs to predict this repair schedule at first. Predictive Testing and Inspection (PTI) is able to generate component condition data with well-monitored so that PTI is often used to create repair schedules using time-based maintenance.

Periodic PTI data retrieval can be used as a comparison of data between components, assists in the process of statistical analysis and determines the trending conditions in each component. So that the result of PTI can be used as one of the indicator in determining each kompoen to its operational period. However, in its application PTI can not be used as the only act of maintenance performed on each component because PTI is not able to overcome the potential of each failure.

2.11.4. 7 Question on Reliability-Centered Maintenance

The implementation of Reliability-Centered Maintenance must be based on 7 main questions related to the system or sub-system observed. The explanation of the 7 main questions are as follows :

1. **System Function:** Does the function of each component meet the expected specifications or standards?

In order to know each component that has met the expected standards, before that the asset owner must determine what performance standards that should accomplised by the component and asset that is able to perform performance in accordance with the specification where the asset owner will operate it. This is why the function becomes the first step in RCM. So, in this case functions are categorized into three types :

a) Primary or primary functions such as: speed, output power, capacity, quality of each product and customer
b) Standard functions or other functions expected to exist in every asset or component such as: safety for users or the environment, protection or efficiency at the time of operation, the integrity of the structure of each asset, as well as the easy controlling asset during operational work.
c) The function of both physical and economic assets in work operations so that the asset owner is able to ensure the contribution of each component within the company.

2. **Functional Failure:** How does the component fail to perform the expected function?

Each component has a different function according to the specifications that have been made by the manufacturer and asset owner always want the components to work according to those specifications for as long as possible. The maintenance actions performed on the component are only capable of keeping the component under initial capability or item capability since it was first created by the manufacturer. And functional failure is a failure of the component or system to meet the system function or the expected work specification.

3. **Failure Mode:** Anything capable of causing a malfunction on each component?

Functional failure that occurs in each component is certainly influenced by several causes. The cause of failure resulting in the component not being able to meet the expected specification is called failure mode. In failure mode not only covers the failure that has occurred but also the failure that may occur on the component. So that in one component or asset can have some failure mode.

4. **Failure Effect:** What is the impact on the component when a malfunction occurs?

After the failure of the function on the component, it is needed to describe the impact of the failure on the work operations. The impacts of such failures can be immediate and long-term failures.

5. **Failure Consequence:** How are the consequences that occur or are caused by damage to each component?

In RCM analysis, failure consequences are classified into four categories :

a) Hidden failure consequences. The consequences of this type of failure do not directly affect the component but if no further identification can cause more fatal damage. This is because the consequences of this failure can not be known directly by the component operator.
b) Safety and environmental consequences. Consequences categorized in this type if the failure that occurs can hurt or eliminate the soul of a person either the operator or the direct party to the component.
c) Operational consequences. Consequences of this type can affect the operational work and production results directly due to several things such as reduced product quality, decreased output power, as well as the cost of improvements during the operation is underway.
d) Non-operational consequences. Consequences that fall into this category if at the time of failure will not affect production operations and safety factors of the operator. But in this case the consequences which arises is the direct cost of repair as a result of the impact of the failure itself.

6. **Proactive Task and Task Interval**: What actions can be taken to prevent or predict each of these failures?

In the RCM analysis, the preventive measures used are grouped into three broad categories :

a) Scheduled On-Condition. This preventive measure involves measuring and observing the components at the time of operation to identify the condition of the component indicating that there is a failure or failure of the function on the component (potential failure). Thus it can be prevented before the consequences of functional failure or greater damage. In the implementation of scheduled on-condition, divided into four main categories, namely Condition monitoring techniques. In this category, special equipment is required to perform inspection or maintenance measures on the components of Statistical process control, ie; prevention techniques carried out by applying the diversity of quality of products produced Primary effect monitoring techniques. In this category in use monitoring inspection equipment in performing its maintenance actions Inspection technique based on predictive and human sense.

b) Scheduled Restoration. Preventive measures in this category are carried out regardless of component conditions whether there is damage or not during the maintenance schedule is underway. This maintenance action requires a special time for the condition of the component must be in a dead or not doing operational work.
c) Scheduled Discard. Preventive action is done by replacing the component at the time of reaching a certain age regardless of the condition of the component has been damaged or not. This can be done under the following conditions: The age of the item is obtained by identifying the possibility of increasing the speed of failure most components have the ability to survive to that age and are performed on all items if component failure has consequences for environmental safety..

7. **Default Action**: What action to take if the corresponding proactive task is not found?

This action is selected when the appropriate and effective proactive task is impossible to do, so it can be interpreted that this action was taken when the failed state. The default action includes several things as follows :

a) Scheduled failure finding. This includes periodic checks on each component to ensure that the functions in the components are in good standing or have been damaged
b) Re-design. This action is done by modifying components and procedures in order to build returns the ability of a component back to the expected function.

Run to failure. This action is done by performing operational work until the component is damaged. This is done when the asset owner has identified and ensured that maintenance measures to prevent damage are not economically comparable (unprofitable). RCM focuses more on the use of qualitative analysis for components that can cause failure on a system. The seven questions above are set forth in the form of Failure Modes, Effects and critical Analysis (FMECA) and RCM Task Decision incorporated in RCM Worksheet.

2.11.5. Failure Mode, Effects, and Criticality Analysis (FMECA)

Failure Modes Effects and Criticality Analysis (FMECA) is a quality tool which builds on the results of Functional Analysis to identify risks and their consequences. FMECA can be applied to systems, products, manufacturing processes, equipment, plant and even less tangible subjects such as logistic or information flows. It is used to identify the possible ways in which failure can occur, the corresponding causes of failure, and the corresponding effects of failure.

Failure Mode, Effects, and Criticality Analysis (FMECA) is a systematic analysis approach, which facilitates the identification of potential problems in a design or process by examining the effects of lower level failure modes. As a result of the analysis, recommended actions are made to eliminate or reduce failures. Also, compensating provisions like adding redundancy for critical systems may be proposed to mitigate risk, if in fact, the failure does occur.

Failure Mode, Effects, and Criticality Analysis (FMECA) also increases knowledge of a system and can improve the cost effectiveness of preventive maintenance programs.

2.11.6. Steps of Failure Mode, Effects, and Criticality Analysis (FMECA) ABS Rules

In MV. Kendari I, the failure analysis of fuel oil system is done by Failure Mode, Effects, and Criticality Analysis (FMECA) using RCM method from ABS Guidance Notes on Reliability-Centered Maintenance. The steps in doing FMECA are as follows:

2.11.6.1. Identification of Operating Modes

The operating process of a system is necessary for the objective and need to be fulfilled by the system. This step included identification of expected function and the performance at vary levels. Operating mode of fuel oil system is condition of a ship expected by the ship owner to be fulfiled each day in all operation mode. The operation mode are divided into four :

1. Full speed condition (at sea)
2. Crowded area condition (in congested area)
3. Manouvering condition (maneuvering alongside)
4. Loading and unloading (cargo handling)

2.11.6.2. Identification of Operating Context

Operating context of the ship is a condition where the system is expected to work given to specified specifications. The operating context should be capable to define :

1. Physical environment where functional group operated.
2. Description of the manner where the functional group used.

3. Specified performance capabilities of the functional group as well as required performance of any additional functional groups within which the functional group is embedded.

Things to consider in compiling the operation context :

a) Serial Redundancy

Equiped to identical standby system/equipment to support an operating functional group. If the system fail, the standby system will activated. The operating contexts for running system/equipment and standby system/equipment are different . A functional failure in operating system/equipment will be evident, while a functional failure in the standby system/equipment will be hidden.

b) Parallel Redundancy

Equiped to systems/equipment that operating at the same time. Each system has the capability to fulfilled the total demand. If there is a functional failure in one system/equipment, the rest of systems/equipment still able continue to operate, but at a higher capacity. In some design, standby systems/equipment may also be in reserve.

c) Performance and Quality Standards

Systems/equipment may be needed to be able working at a certain performance level or to provide a service with a certain quality level.

d) Environmental Standards

To fulfill international, national and local laws and regulations.

e) Safety Standards

Chance of hazards that might be exist in an operating context and the safeguards that must be in place for protection of the crew.

f) Shift Arrangements

It is assumed the propulsion system of seagoing ship is operating continuously, except the docking period. The ship’s service electrical power system is also operating continuously. System arrangements and maintenance strategies must be designed carefully to ensure system reliability.

2.11.6.3. Identification of Functional Failure and Failure Effect

In this analysis, the failure type means that the system of an element fails. This illustrate the operation activities along with the functional dependence of component failures that occur. In applying FMECA, all functional failure of the component will be analyzed by check out the failure effect at the next high level. This is to measure the effect on overall system performance, so that components and systems must clearly defined.

2.11.6.4. Determine the Failure Mode

This analysis include all process or output expected to limit the cause of the failure. FMECA is expected to be able to support the identification process of other potential causes of failure. The analysis process in this step can use the previous historical failure data.

2.11.6.5. Determine the Severity Level

This step show the consequences caused by the failure mode. In ABS Guidance Notes on Reliability-Centered Maintenance the definition of classification of effect failure is divided into four types :

1. Minor, Negligible

   Will not cause loss of personnel or systems, but results in the need of some corrective maintenance.

2. Major, Marginal, Moderate

   Might cause personnel loss, system malfunction and system functional degradation.

3. Critical, Hazardous, Significant

   Might cause serious losses, significant system damage and functional loss of the system.

4. Catastrophic, Critical

   A failure that can lead to loss of life and loss to a system as a whole.

2.11.6.6. Determine the Current Likelihood

In this step a frequency analysis of each individual failure is performed. The following is a category of failure frequency (current likelihood) as in **Table 2.5.**

Table 2.5. *Probability of Failure (Frequency, Likelihood)*

Likelihood Descriptor	Description
Improbable	Less than 0.001 events/year
Remote	0.001 to 0.01 events/year
Occasional	0.01 to 0.1 events/year
Probable	0.1 to 1 events/year
Frequent	1 or more events/year

1. Improbable

The probability of a single failure on each component operation is very small. The frequency of failure of this type is in the range of 0.0001 - 0001 of the overall occurrence of component failure in one year (365 days).

2. Remote

The probability of a single failure on each component operation is small. The frequency of failure of this type is in the range of 0.001 - 0.01 of the overall occurrence of component failure in one year (365 days).

3. Occasional

The probability of a single failure against each component operation is possible sometimes. The frequency of failure of this type is in the range 0.01 - 0.1 of the overall occurrence of component failure in one year (365 days).

4. Probable

The probability of a single failure on each component operation is possible. The frequency of failure of this type is 0.1 - 1 of the overall component failure events in one year (365 days).

5. Frequent

The probability of a single failure on each component operation of serine occurs. The frequency of failure of this type lies in more than 1 of the overall occurrence of component failure in one year (365 days).

2.11.6.7. Analyze the Current Risk

In this step there is the preparation of risk matrix. Risk matrix is a risk level table organized based on combination of consequence level and frequency of failure. The standard used to determine the risk matrix is derived from ABS Guidance Notes on Reliability-Centered Maintenance as in **Table 2.6.**

Table 2.6. *ABS Risk Matrix*

Critical	4		HIGH RISK			
Hazardous	3		MEDIUM			
Major	2			RISK		
Minor	1	LOW RISK				
		LIKELIHOOD				
		1	2	3	4	5
		Improbable	Remote	Occasional	Probable	Frequent

If all stages in the analysis of failure mode, effects, and criticality analysis have been completed. So then the results of the analysis need to be documented into the worksheet as in **Table 2.7.** and **Table 2.8.**

Table 2.7. *Bottom-Up FMECA Worksheet (1)*

BOTTOM-UP FMECA WORKSHEET						
No.	Description : FO Transfer Pump					
Item (1)	Failure Mode (2)	Causes (3)	Failure Char. (4)	Local Effects (5)	Functional Failures (6)	End Effects (7)

Table 2.8. *Bottom-Up FMECA Worksheet (2)*

BOTTOM-UP FMECA WORKSHEET				
Description : FO Transfer Pump				
Matrix (8)	Severity (9)	Current Likelihood (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)

2.11.7. Maintenance Task Selection Analysis

In this analysis shown the task selection flow diagram contained in the ABS Guidance Notes on Reliability-Centered Maintenance. Task selection flow diagram used as a logic tree analysis to help the selection of the most suitable management strategies to deal with existing failures. Thus the failure can be prevented.

2.11.7.1. First Selection Decision

Decide whether the risk associated with the failure mode is the highest or lowest risk and determine the confidence in the decision.

1. Highest Risk
   A failure with highest risk normally cannot reach an acceptable level of risk only through maintenance. In general, to achieve an acceptable level of risk, we need to make a change the fundamental, like how the equipment is designed or operated. A one-time change is needed to reduce the risk. Once the one-time change is identified, the FMECA must be updated and any applicable failure reevaluated using the RCM Task Selection Flow Diagram.
2. Lowest Risk
   A failure with the lowest risk is a low-priority failure and acceptable without any failure management strategy for most organizations.
3. Confidence in The Risk Characterization
   High confidence show that the team is quite sure that the risk is properly defined and can be used in the RCM flow diagram without any further consideration. Low confidence shown that the team is uncertain and that additional data (about the probability or consequence of the failure) are required before the risk can be used in the decision-making process. Failure mode is assumed to have a medium risk characterization and is evaluated through RCM Task Selection Flow Diagram.

2.11.7.2. Second Selection Decision

Condition-monitoring tasks are considered because these tasks are the best option technically and usually the most cost-effective. To deckde if failure can be managed by a condition-monitoring task, the team must choose a specific task and then decide an suitable task interval. The following provide criteria for making these decisions :

1. Maintenance Task Selection Criteria

A condition-monitoring task must be applicable and effective. When determining the applicability and effectiveness, here is the consideration :

- Practicable to implement (e.g., maintenance task interval and accessibility for carrying out the task).
- High degree of success in detecting failure.
- Cost-effective. The cost of undertaking a task over a period of time must be less than the total cost of the consequences of failure. The costs include man-hours, spares, tools and facilities, and should be assessed on the basis of through-life costs.

Next, the team must evaluate the potential risk reduction resulting from applying the condition-monitoring task. This can fulfilled by decide the reduction in risk that is anticipated if the task is applied. Proactive maintenance tasks will reduce the probability of failure rather than the severity of the consequence. The reduced risk is then compared to the risk acceptance criteria to decide whether the task should be choosed.

If the risk reduction does not pass an acceptable level of risk, the failure mode is considered to decide if other maintenance tasks or a one-time change is required to manage the failure.

2. Maintenance Task Interval Determination

Ideally, proactive maintenance task intervals are decided using real failure data, but for most cases it is not realistic. Thus the task frequency can be determined from the following sources list :

- Generic P-F interval data.
- Manufacturers' recommendations.
- Current task intervals.
- Team experience.

For condition-monitoring tasks, the task interval must give enough notification of the failure to make sure the action can be taken in time to prevent the consequences. The maintenance task interval must be set at less than half the anticipated P-F interval.

2.11.7.3. Third Selection Decision

Decide whether the failure mode is an evident or a hidden failure mode.

1. Evident Failures

An evident failure is one that will later on become evident to the operating crew under normal operating conditions (NOC) (e.g., the loss of function will be noticed at some future, indefinite time without any further incident or intervention).

2. Hidden Failures

A hidden failure is a failure that will not become evident to the operating crew if the failure mode occurs. Normally, hidden failures only become apparent after a second but related failure or event occurs. For example, the failure of a protective device that is not fail-safe is a typical hidden failure. Although there will be no direct consequences of a hidden failure, the consequencen of such a failure will be an increased risk of multiple failures.

If the failure is hidden and there is no condition monitoring, planned maintenance or combination of tasks that will make an acceptable risk level, the team must decide which failure-finding task is needed to manage the failure.

2.11.7.4. One-Time Changes

If there is no failure-finding task that will provide an acceptable risk level, the team must decide then determine which of the tasks (or combination of tasks) provides the best failure management strategy. If the team determines that the risk can be lower than what can be achieved with maintenance, the team should consider one-time changes to manage the failure. To evaluate the effectiveness of one-time changes, the team should determine the potential changes and consider :

1. Acceptable level
2. Reduction of risk to a tolerable level with no further risk reduction.
3. Cost-effectiveness
4. Possibility of maintenance task

2.11.7.5. Rounds and Routine Servicing

In addition to maintenance recommendations above, rounds and routine inspection tasks should be determined. These important tasks help make sure the failure rate curve for the failure mode (that is the basis for the proactive maintenance tasks and risk characterization) is not altered.

2.11.8. Maintenance Task Allocation and Planning

Maintenance task allocation and planning is one of the outputs of this final project. In this research the authors are guided on ABS Guidance Notes on Reliability-Centered Maintenance.

1. Task Categories

   The maintenance tasks derived from the RCM analysis are to be allocated in accordance with the following categories :

- Category A
  Can be undertaken at sea by the vessel's crew.
- Category B
  Must be undertaken alongside by equipment vendors or with use of dockside facilities.
- Category C
  Must be undertaken in a dry dock facility.

2. Task Interval Adjustment

Task intervals derived from the RCM analysis need not be in alignment with the current calendar-based maintenance schedule. Therefore, the team should integrate these task intervals into a normal maintenance schedule. For this purpose, RCM task intervals may have to be adjusted to a shorter or longer interval depending on the criteria given below :

- Tasks with safety/environmental consequences should only be adjusted to a shorter task interval to ensure that safety and containment are not compromised
- Tasks with operational consequences may be adjusted to a longer or shorter task interval. However, when adjusting to a longer interval, the team should obtain the approval of the responsible person in the shipping company.

In performing the analysis at this step is required maintenance task selection worksheet as in **Table 2.9.** and **Table 2.10.**

Table 2.9. *Maintenance Task Selection Worksheet (1)*

No.				**Description : FO Transfer Pump**		
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effects (5)		
				Local	Functional Failure	End

Table 2.10. *Maintenance Task Selection Worksheet (2)*

Description : FO Transfer Pump						
Risk Characterization (6)			Task Selection (7)			
Severity	Current Likelihood	Current Risk	Proposed Action(s)	Projected Likelihood	Projected Risk	Disposition

Category B and C task intervals should be organized to derive a maintenance schedule. Adjusting the RCM task intervals (Category B and C tasks only) using the criteria specified in Category B so that the tasks can at the same time with the vessel's port calling and dry-docking schedules.

After all the steps in the analysis of maintenance task allocation and planning has been completed, then the next need to be made conclusions from the results of the analysis. Here is a summary of maintenance tasks such as **Table 2.11.**

Table 2.11. *Summary of Maintenance Tasks*

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category:							
Functional Group:							
System:							
Equipment Item:							
Component:							
Task	Task Type	Item No.	Risk		Frequency	Procedure No. Or Class Reference	Comments
			Current	Projected			

2.12. Schedule and Maintenance Cost

Good maintenance will be done within a certain time and at the time of production process is not running. The more frequent the maintenance of a machine will increase the maintenance cost. On the other hand if maintenance is not done will reduce the working performance of the machine. The optimal maintenance pattern needs to be sought so that between maintenance cost and damage cost can be balanced on the minimum total cost.

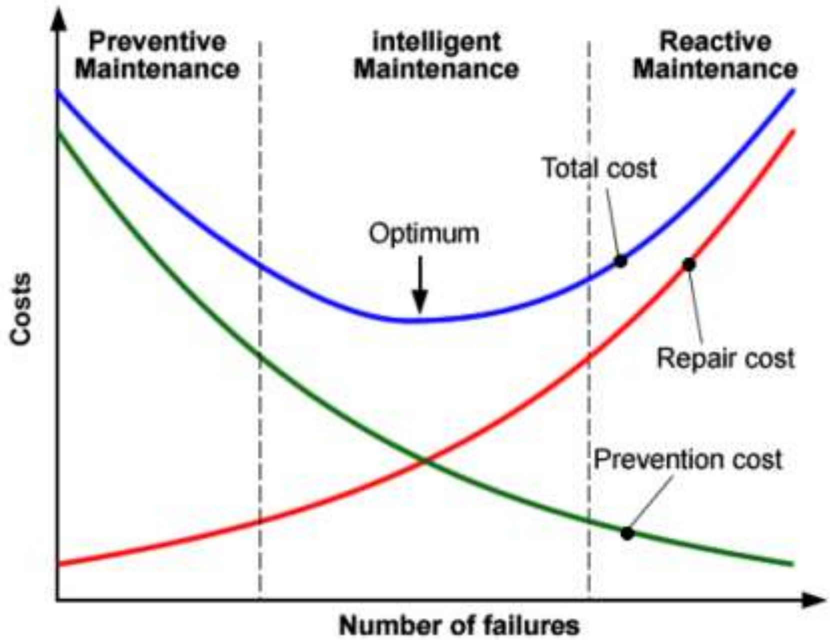

Figure 2.13. *Graph of Relation Between Cost and Maintenance Level*

Preventive Cost is a cost incurred due to a machine maintenance that is already scheduled. While Failure Cost is a cost that arises because there is damage beyond estimation that causes the production machine stalled production time is running.

For optimization of time and cost of preventive maintenance based on lifetime can be obtained by using the following formula (Vajda, 1973) :

$$Tc(tp) = \frac{Cp\ x\ R(tp) + Cf\ x\ (1 - R(tp))}{tp\ x\ R(tp) + \int_0^{tp} t\ x\ f(t)\ dt}$$

Where :

Tc(tp) : Total Cost at The Time

Cp : Preventive Cost

Cf : Failure Cost

tp : Time

R(tp) : Reliability Function at The Time

To help ensure that the RCM stages consistently applied, a structured analysis process is applied. The next chapter will be describing the methodology of this Final Project.

CHAPTER III
METHODOLOGY

Methodology represents of the basic framework from stages to finish the final project. The methodology of this final project cover all of the activity that supports the completion of this final project. The stages of this methodology are as follows as in **Figure 3.1.** and **Figure 3.2.**

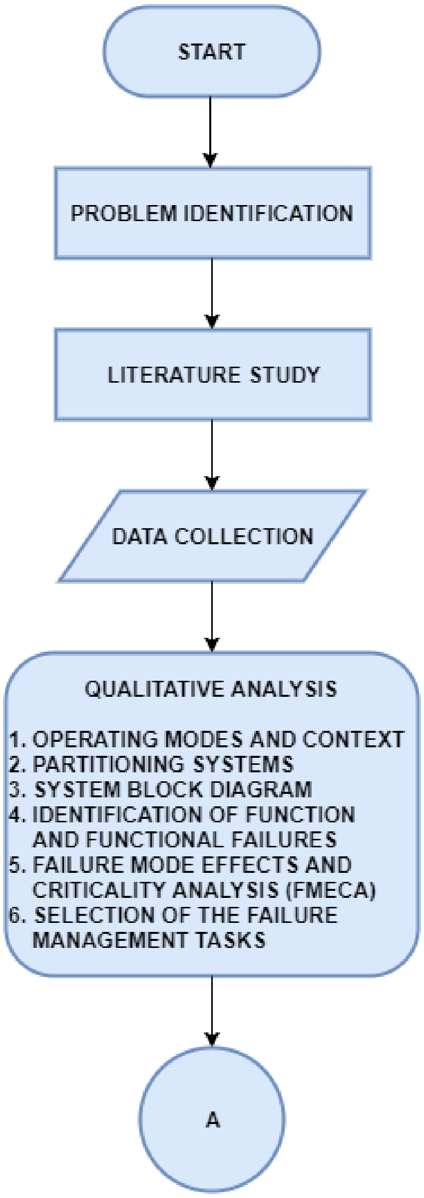

Figure 3.1. *Methodology Chart (1)*

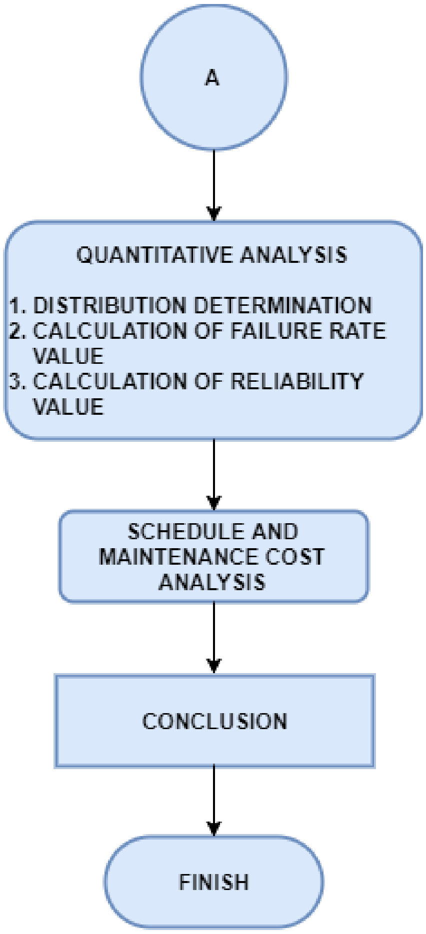

Figure 3.2. *Methodology Chart (2)*

Explanation of the stages of this methodology is as follows:

3.1. Problem Identification

This first stage identifies the problems in the vessel. The object of research taken in the final project is Fuel Oil System on MV. Kendari I PT Meratus Line. Fuel Oil System is one of the main systems on board that support ship operations. In order for the system to work optimally it needs optimal maintenance so that the potential for failure can be reduced. The problem on the final project can be identified after interview with company's collaborator. The interview is about how the maintenance process on the ship.

In this final project, failure analysis of Fuel Oil System is done qualitatively with Reliability-Centered Maintenance (RCM) method. Furthermore, to find out how the risk of failure can occur and the extent of the impact caused on ship operations need to perform a failure analysis of Failure Modes, Effects and Critivality Analysis (FMECA) using ABS rules. The last one is to perform Maintenance Task Allocation and Planning analysis on each component.

3.2. Literature Study

The next stage is to conduct a literature study with aim to explaining the depth of review, summarizing the basic theory, general and specific reference, and obtaining various other supporting information related to the final project. In this final project, the authors conducted a literature study on Reliability-Centered Maintenance (RCM) obtained from books, journals, papers, and from the internet that support this final project.

Furthermore the authors determine the standards used in RCM method analysis that is by using ABS Guidance Notes on Reliability-Centered Maintenance. In addition the authors also held discussions with interested and competent parties in this final project. So with the completion of this stage, obtained some of the results are the supporting literature in this final project, the method used in this final project, the recommendation of research object from the company, as well as some list of data required in this final project.

3.3. Data Collection

The data needed for the analysis with the RCM method in this final project is qualitative data to answer questions that refer to RCM ABS rules. In the final project, the authors make observations to PT Meratus Line in obtaining data from MV. Kendari I. The data used for RCM analysis include:

1. General info of the ship and the machineries used to know in detail the condition of the ship. Ship specification data and system components are taken directly at PT Meratus Line.
2. Initial system design of the fuel oil system is used to evaluate the reliability of ship components and to know the location of the component system.
3. Planned maintenance system of the fuel oil system used to evaluate the reliability of ship components. The data is obtained from PT Meratus Line.
4. Maintenance costs of the fuel oil system used to evaluate maintenance costs between existing maintenance and reliability-centered maintenance.

3.4. Qualitative Analysis

Qualitative analysis method is a method that will be done by evaluating the function of a component, functional failure, FMECA, the consequences of a failure and what actions should be done. Qualitative analysis is conducted interviewing and consulting with company's collaborator. As for the explanation of each stage is as follows:

3.4.1. Operating Modes and Context

Operating mode of Fuel Oil System is a working characteristic of Fuel Oil System used in every operational work. Operating mode depends on the type of activity as well as the environmental factors of the ship's operations. Where in the final project is divided into four categories, namely: at sea, in congested area, maneuvering alongside, and cargo handling. Where in the four categories there are three main characteristics are:

a. Environmental Parameters

In this research, data related environmental factors or operational areas of the MV. Kendari I PT Meratus Line.

b. Manner of Use

In this research, data related to the work and operational systems of MV. Kendari I PT Meratus Line.

c. Performance Capability

In this research, data related to the performance of Fuel Oil System on MV. Kendari I PT Meratus Line.

Operating context of ship is a condition where the system in the ship is expected to work in accordance with the specified specification so as to achieve the existing function. Then the operating context in this study is determined based on the results of interviews with the company's collaborator. The results of these interviews obtained work specifications that are expected to appear in the operational period.

3.4.2. Partitioning Systems

The vessel is first partitioned into disciplines and functional groups beginning with hull, machinery and utilities, and cargo handling. After that the system-level partitioning includes two indenture levels: subsystems and equipment items. This partitioning establishes the boundaries for each discipline and lower levels of indenture. In addition, the partitioning provides a basic structure for defining the vessel's operating characteristics.

3.4.3. System Block Diagram

System Block Diagram serves as an aid to visualise the structure and guides to identify the various functions that must be performed by the system. The System Block Diagram simplifies system design and operation for clarity and understanding.

3.4.4. Identification of Function and Functional Failures

The next stage is the identification of the asset functions meaning the analysis what the asset must do. Each function should be documented as a function statement. According to Moubray the function statements in general shall contain a verb describing the function, an object on which the function acts and a performance standard. After this is the identification of the possible functional failures of the functions. A functional failure is defined as the inability of any asset to fulfill a function to a standard of performance which is acceptable to the user.

3.4.5. Failure Mode, Effects, and Criticality Analysis (FMECA)

For this stage, the failure mode, effects and criticality analysis is probably the key aspect of the Reliability-centered Maintenance (RCM) analysis process. It is generally a reliability tool to identify failure modes that would adversely affect overall system reliability. The purpose of this step is to establish the cause and effect relationship among potential equipment failures as well as functional failures and the effect of the functional failures.

Thesse relationships are needed to define maintenance requirements and other improvements. Finally, the detectability and criticality of the postulated failure mode effects must be evaluated. In general, two approaches for the FMECA are possible. The bottom-up approach starting from the lowest level of indenture identified during the system partitioning and a top-down approach, starting from the top level. By following the RCM approach defined by the ABS the author will use the bottom-up approach for Failure Mode Effects and Criticality Analysis (FMECA) analysis.

3.4.6. Selection of The Failure Management Tasks

Failure management tasks as one of the preventive maintenance guidelines serves to organize, plan, and as a guide in every maintenance activity performed on the ship along with the existing components. The failure management tasks are structured according to the standards or rules that are followed in order to maintain the function and extend the lifetime before any damage occurs. In this case the regulation and recommendation of maintenance activity of each component on failure management tasks using ABS Guidance Notes on Reliability-Centered Maintenance standard.

In this stage, the analysis is based on the results of the previous FMECA analysis. Based on the result of the analysis, it is determined the proposed actions or the recommended maintenance actions to the failure. It is hoped that with the application of proposed actions well, the condition of the component may return as before or meet the specific needs of the component itself.

3.5. Quantitative Analysis

Quantitative analysis method is a method to evaluate type of distribution on each component, the value of failure rate, and the value of reliability. Here are the steps taken to process the data with quantitative methods.

3.5.1. Distribution Determination

To determine the distribution type of each component the first thing to do is to determine the time to failure (TTF) of each component. Determination of TTF value is obtained from the maintenance data on the components of Fuel Oil System on MV.Kendari I with a span of time from January 2011 to October 2017.

After that the second thing determines the mean time to failure (MTTF) of each component. The determination of MTTF value is obtained from the sum of TTF values divided by the number of maintenance performed from January to 2011 until October 2017.

Determination of distribution aims to obtain the value of the possibility of damage at any given time. Determination of time to failure distribution can be done by using ReliaSoft Weibull ++ Version 6 software. The advantage of this software is able to determine various types of data distribution be it data exponential distribution, weilbull distribution 2-3 parameters, normal distribution, and lognormal distribution. Here are the steps to determine time to failure distribution :

- Determining analysis method.

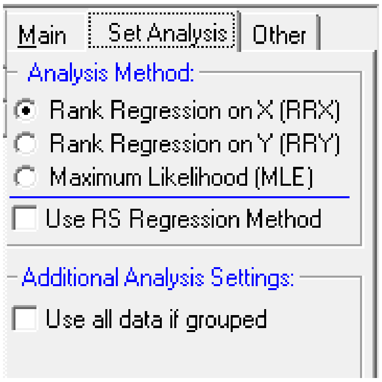

Figure 3.3. *Analysis Method on ReliaSoft Weibull++ Version 6*

- Entering data between failures to be searched for distribution.

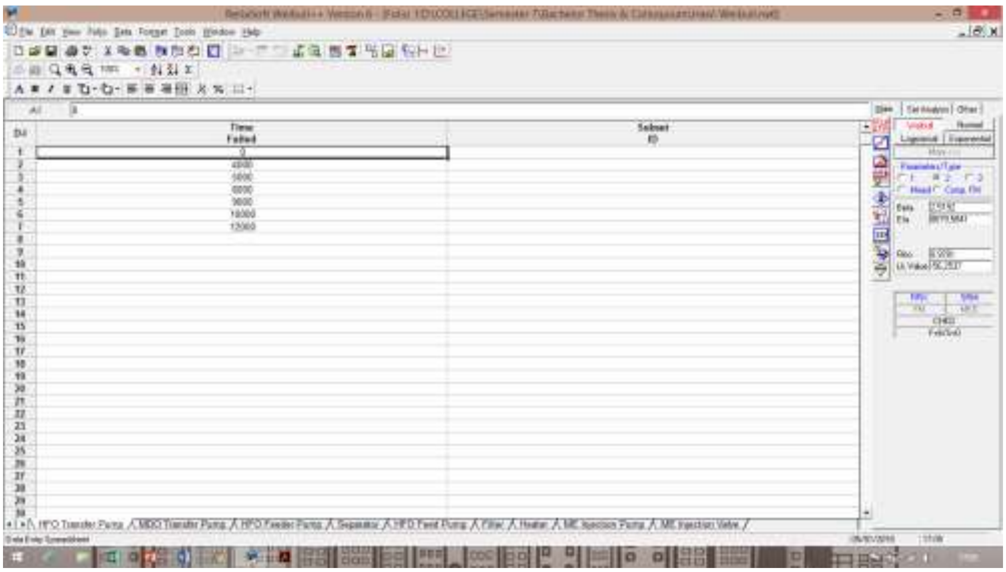

Figure 3.4. *Entering TTF Data*

- Begin the distribution test by selecting the option distribution wizard to obtain the average goodness of fit parameter (AVGOF) where the greater the value in this column indicates the mismatch of the distribution test results, the average of plot fit parameter (AVPLOT) showing the size used to plot the test result value distribution and likelihood test function parameter (LKV), the smallest value is the best value for the test result of the distribution.

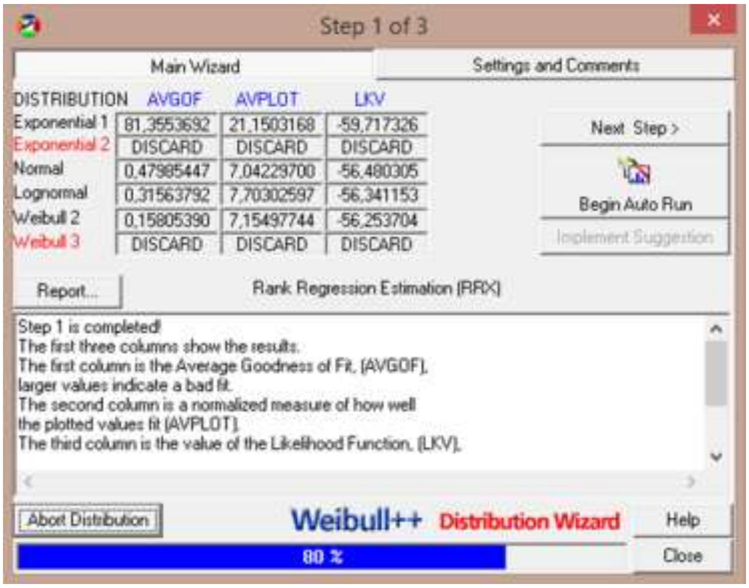

Figure 3.5. *Distribution Testing*

- The best distribution test results can be seen in the Begin Auto Run option. In each distribution, shows the ranking result. The ranking on the smallest order shows the best distribution results.

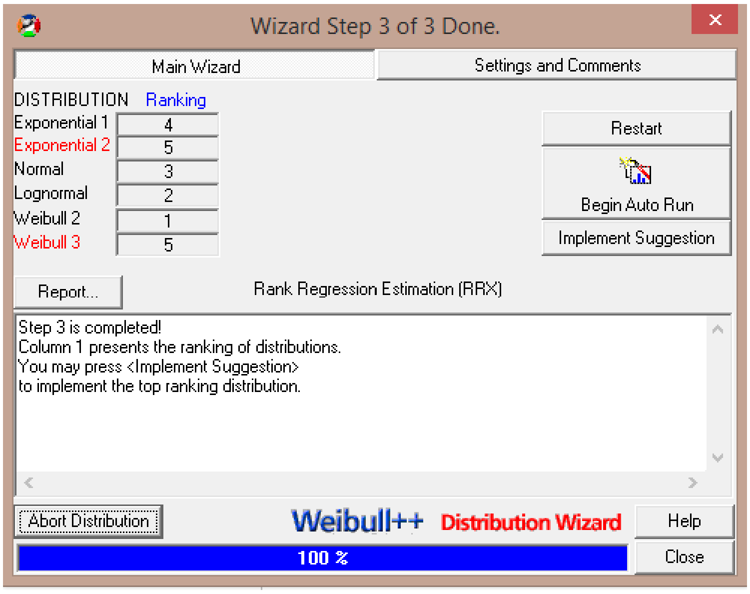

Figure 3.6. *Ranking on Each Distribution*

- In the last step there is an implementation suggestion that shows the distribution and distribution parameters of the data being tested. The determination of parameters is adjusted to the previous best distribution results. The test distribution may include normal distribution, lognormal, exponential 1 parameter, exponential 2 parameters, weibull 2 parameters, and weibull 3 parameters. The test results obtained parameters of failure of the distribution.

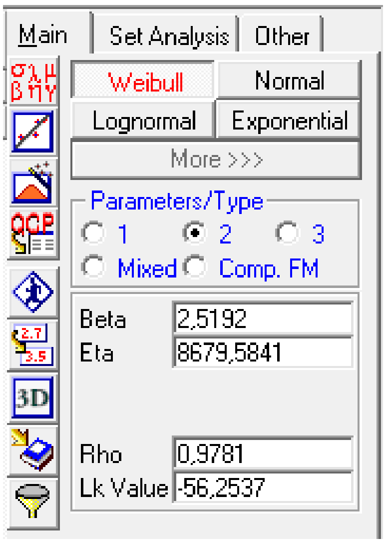

Figure 3.7. *Parameter of Distribution*

3.5.2. Calculation of Failure Rate Value

Based on the determination of test parameters using ReliaSoft Weibull++ Version 6 can determine failure rate by using the existing equations. The results of the failure rate calculation can be plotted in a graph of the relationship between failure rate value λ(t) with operational time.

3.5.3. Calculation of Reliability Value

Based on the determination of test parameters using ReliaSoft Weibull++ Version 6 can determine reliability by using the existing equations. The results of the reliability calculation can be plotted in a graph of the relationship between Reliability value R(t) with operational time.

3.6. Schedule and Maintenance Cost Analysis

Maintenance costs in this case is used in every maintenance action performed, in this case it is assumed that the preventive maintenance schedule can recover the system as in new condition. The analysis of schedule and maintenance cost in this final project use equation on **Section 2.12.**

CHAPTER IV
DATA ANALYSIS

4.1. Identification of Data Collection

PT Meratus Line as a service provider of container-liner services between the islands in Indonesia has several container vessels as one of the company's economic assets. In **Section 3.3.** it has been explained that the first step taken in this study is data collection. The data consists of:

1. General info of the ship and the machineries

   This data is used as the basis of research object and reference in FMECA analysis phase include identification of failure effect, functional failure, and main engine characteristic. This data will be explained further in **Section 4.1.1.**

2. Initial system design of the fuel oil system

   This design is used as a consideration in identifying the impact or consequence of each failure mode that occurs. This data is described further in **Section 4.2.3.**

3. Planned maintenance system of the fuel oil system

   This data is taken during 2011-2017 and is used as one of the reference in determining failure mode analyzed. This data is described further in **Section 4.2.5.**

4. Maintenance costs of the fuel oil system

   This data is taken during 2011-2017 and is used as a reference in comparing maintenance costs between existing maintenance and reliability-centered maintenance. This data is described further in **Section 4.4.**

4.1.1. Research Object

The first step of the Reliability-Centered Maintenance method is to choose what are to be analyzed. After interviewed with the company’s collaborator by arguing with the points outlined in **Section 3.1.2.**, the fuel oil system was selected. As vessel under research MV. Kendari I will be used. Here is presented MV. Kendari I in **Figure 4.1.** and **Figure 4.2.** The next step is to collect data about general info of the ship and machineries. The following general info and machineries from MV. Kendari I presented in **Table 4.1.** and **Table 4.2.**

Figure 4.1. *MV. Kendari I (1)*

Figure 4.2. *MV. Kendari I (2)*

Table 4.1. *General Info of MV. Kendari I*

General Info	
Previous Name	Dagmar
Owner	PT Mandiri Abadi Sentosa
Operator	PT Meratus Line
Built	1991
Builder	Mawei Shipyard, Fuzhou
Kind Of Ship	General Cargo, equipped to carry container-heavy cargo
Call Sign	PNWH
Flag	Indonesia
Port of Registry	Surabaya
IMO-Number	9064695
Class	BKI
Official Number	2011 Ka No.4439/L
Gross Tonnage	5737
Length Over All	120 m
Length Perpendicular	111 m
Beam	20 m
Depth Moulded	8 m
Speed	14 Knots

Table 4.2. *Machineries of MV. Kendari I*

Machineries	
Type of Propulsion	CPP, dia.3500 mm, 4 blades, KAMEWA
Main Engine	MAK
Engine Model	9M 453C
Power	3300 kw
Auxilary Engines	MAN
Engine model	D2840 LE

4.2. Qualitative Analysis

In this final project research, qualitative analysis conducted on each component of the compiler fuel oil system is an explanation of operating modes and context, partitioning system, system block diagram, function and functional failure and then followed by the data processing presented in FMECA and selection of the failure management tasks. This qualitative analysis as supporting data on how to take action during maintenance.

4.2.1. Identification of Operating Modes and Context

The first stage of qualitative analysis is the identification of operating modes and contexts of the fuel oil system. Operating modes are the characteristics or operational conditions of the vessel to be achieved. While operating contexts are the physical reference of where and how the operation mode is run. Based on the table below described the operating mode and operating context on the fuel oil system that has been prepared based on the steps in **Section 3.4.1.**

Table 4.3. *Operating Modes and Context of HFO Transfer Pump*

Operating Context of HFO Transfer Pump	
The transfer of the HFO from the HFO storage tank to the settling tank realised by one screw pump. The type is SLF660ER40U12 manufactured from Allweiler. If a failure in one of the HFO transfer pump occurs, the pressure loss can be noticed on the pressure gauge. The HFO/MDO transfer pump will be work alternately.	
Common Characteristics	Operating Modes
	On Sea / Maneuvering
Environmental Parameters	Settling of the fuel oil is only a pre-cleaning procedure. According Meratus in case the purifiers could operate with unsettled HFO. The correct operation of the pumps can be checked through the pressure gauges of the pumps in the engine room.
Manner of Use	HFO has 1 transfer pump. The HFO transfer pump is operated for filling procedure from storage tank to settling tank.
Performance Capability	The performance capability of the HFO transfer pump on project guide: Capacity: 30 m^3/h Pressure: 4 bar Speed: 1450 rpm Power: 15 kw, 380 V, 50 Hz

Table 4.4. *Operating Modes and Context of MDO Transfer Pump*

Operating Context of MDO Transfer Pump	
The transfer of the MDO from the MDO storage tank to the service tank realised by one screw pump. The type is SLF210ER40U12 manufactured from Allweiler. If a failure in one of the MDO transfer pump occurs, the pressure loss can be noticed on the pressure gauge. The HFO/MDO transfer pump will be work alternately.	
Common Characteristics	Operating Modes
	On Sea / Maneuvering
Environmental Parameters	The correct operation of the pumps can be checked through the pressure gauges of the pumps in the engine room.
Manner of Use	MDO has 1 transfer pump. The MDO transfer pump is operated for filling procedure from storage tank to servive tank.
Performance Capability	The performance capability of the MDO transfer pump on project guide: Capacity: 12 m^3/h Pressure: 4 bar Speed: 1400 rpm Power: 3 kw, 380 V, 50 Hz

Table 4.5. *Operating Modes and Context of Separator*

Operating Context of Separator	
The separation of the HFO between the settling tank and the service tank is realized by one of the two separators. The type is MMPX 304 SGP-11 manufactured from Alfalaval operated under parallel redundancy.	
Common Characteristics	Operating Modes
	On Sea / Maneuvering
Environmental Parameters	The self-cleaning process is operated with water, opening and closing the bowl. The separator is fed with HFO by a gear pump which is driven by separator motor.
Manner of Use	Separator no. 1 is used for one voyage, the other one is on standby. For the next voyage separator no. 2 is used for duty. Anticipated annual service hours for both pumps are the same.
Performance Capability	The performance capability of the separator on project guide: Max capacity: 1.5 m^3/h Max speed: 9510/min The separator operations and the sludge discharge are automatically controlled by a timer.

Table 4.6. *Operating Modes and Context of Heater*

Operating Context of Heater
The heater for oil heating is provided by the economizer system which utilizes the exhaust gas engine . The oil heater is located behind separator. Operating temperature of HFO inside the separator is between 80-85°c.

Table 4.7. *Operating Modes and Context of HFO Feeder Pump*

Operating Context of HFO Feeder Pump	
The HFO feeder pump and circulating pump that using gear pumps. The type is PF25S manufactured from Trik Pumpen Kiel. The HFO feeder pump are provided with a standby pump and the unit is equipped with an automatic standby function.	
Common Characteristics	Operating Modes
	On Sea / Maneuvering
Environmental Parameters	The correct operation of the pumps can be checked through the pressure gauges of the pumps in the engine room.
Manner of Use	The HFO feeder pumps are operated as follows: the no. 1 pump is operated for one voyage at a time with the no. 2 pump on standby. After the voyage, the no. 1 pump is secured and put on standby and the no.2 pump is operated for the next voyage. Anticipated annual service hours for both pumps are the same.
Performance Capability	The performance capability of the HFO feeder pump on project guide: Capacity: 1.5 m^3/h Pressure: 5 bar Speed: 1450 rpm Power: 7 kw

Table 4.8. *Operating Modes and Context of HFO Circulating Pump*

<table>
<tr><th colspan="2">Operating Context of HFO Circulating Pump</th></tr>
<tr><td colspan="2">The HFO circulating pump that using gear pumps. The type is PF25S manufactured from Trik Pumpen Kiel. The HFO circulating pump are provided with a standby pump and the unit is equipped with an automatic standby function.</td></tr>
<tr><td rowspan="2">Common Characteristics</td><td>Operating Modes</td></tr>
<tr><td>On Sea / Maneuvering</td></tr>
<tr><td>Environmental Parameters</td><td>The correct operation of the pumps can be checked through the pressure gauges of the pumps in the engine room.</td></tr>
<tr><td>Manner of Use</td><td>The HFO circulating pumps are operated as follows: the no. 1 pump is operated for one voyage at a time with the no. 2 pump on standby. After the voyage, the no. 1 pump is secured and put on standby and the no.2 pump is operated for the next voyage. Anticipated annual service hours for both pumps are the same.</td></tr>
<tr><td>Performance Capability</td><td>The performance capability of the HFO circulating pump on project guide:
Capacity: 1.5 m^3/h
Pressure: 5 bar
Speed: 1450 rpm
Power: 7 kw</td></tr>
</table>

Table 4.9. *Operating Modes and Context of Filter*

Operating Context of Filter
The HFO system is equipped with two type of filter consist of duplex filter for removing large impurities from HFO and indication of failures in purification system. Another type of filter is auto filter for removing small impurities from HFO. The MDO system is equipped with one duplex filter for removing large impurities from MDO and indication of failures in purification system. For both fuel types, fuel oil filter is located in front of the main engine/auxiliary engine. The indicator of filter must be checked by the crew in the engine room. Filters can according to class be cleaned without interrupting the fuel supply.

Table 4.10. *Operating Modes and Context of Main Engine Injection Pump*

Operating Context of Main Engine Injection Pump
A classical single-plunger injection design, one pump element per cylinder is used. Fuel injection pressure is around 380 bar. Before entering engine, fuel must have a viscosity between 10 cst to 12 cst. Following inspection Main Engine Injection Pump is available on the ship: • Cylinder pressure measurement equipment.

Table 4.11. *Operating Modes and Context of Main Engine Injection Valve*

Operating Context of Main Engine Injection Valve
The injection nozzle is a multiple staggered injection hole type. Following inspection Main Engine Injection Valve is available on the ship: • A nozzle tester to test injection spray pattern, injection pressure and leakage of the injection nozzle.

4.2.2. Preparation of Partitioning Systems

The next stage is the preparation of partitioning system. As described in **Section 3.4.2.** because in the ship there are many complex systems, it is necessary to classify into the system functions. Classification is based on discipline, functional group, system, sub system, and components presented as in **Appendix 1**.

4.2.3. Identification of System Block Diagram

System block diagram is a method used to present the interconnection of functions between systems and components in a fuel oil system. With the system block diagram can also be known effects and sequence of events that will likely occur due to the failure of an asset or component. So if there is a failure, the system or other components that will be affected to the failure can be known from the system block diagram. The system block diagram in this final project is presented in **Appendix 2**.

4.2.4. Identification of Function and Functional Failure

The next step is to identify the function of the fuel oil system. This stage is done to find out what function there is and expected the owner of fuel oil system along with the failure of the function. Identification of the function of fuel oil system can be done by guiding on several things such as owner requirements.

In addition to identifying the function of the fuel oil system, the final project identifies the functional failure of the fuel oil system which is defined as the inability of the fuel oil system to fulfill the functions required by PT Meratus Line. Based on the explanation in section 3.4.4. then the results obtained as in the table below.

Table 4.12. *Function and Functional Failure of HFO Transfer Pump*

HFO Transfer Pump				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
1.	To deliver HFO from the HFO storage tank to HFO settling tank with capacity of 30 m^3/h.	Primary	1.1.	HFO transfer pump does not produce capacity of 30 m^3/h at the time of operation.
			1.2.	HFO transfer pump produces less than capacity of 30 m^3/h at the time of operation.

Table 4.13. *Function and Functional Failure of MDO Transfer Pump*

MDO Transfer Pump				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
2.	To deliver MDO from the MDO storage tank to MDO service tank with capacity of 12 m^3/h.	Primary	2.1.	MDO transfer pump does not produce capacity of 12 m^3/h at the time of operation.
			2.2.	MDO transfer pump produces less than capacity of 12 m^3/h at the time of operation.

Table 4.14. *Function and Functional Failure of Separator*

Separator				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
3.	To separate the dissolved water, impurities and sludge from the fuel oil with capacity of 1.5 m^3/h.	Primary	3.1.	Separator does not separate the dissolved water, impurities and sludge from the fuel oil with capacity of 1.5 m^3/h.
			3.2.	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m^3/h.

Table 4.15. *Function and Functional Failure of Heater*

Heater				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
4.	To heating the fuel between 80-85°c.	Primary	4.1.	Heater heating the fuel less than between 80-85°c.

Table 4.16. *Function and Functional Failure of HFO Feeder Pump*

HFO Feeder Pump				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
5.	To deliver fuel from the HFO service tank to the mixing tank with capacity of 1.5 m^3/h.	Primary	5.1.	HFO feeder pump does not produce capacity of 1.5 m^3/h at the time of operation.
			5.2.	HFO feeder pump produces less than capacity of 1.5 m^3/h at the time of operation.

Table 4.17. *Function and Functional Failure of HFO Circulating Pump*

HFO Circulating Pump				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
6.	To deliver fuel from the mixing tank to the fuel injection system with capacity of 1.5 m^3/h.	Primary	6.1.	HFO circulating pump does not produce capacity of 1.5 m^3/h at the time of operation.
			6.2.	HFO circulating pump produces less than capacity of 1.5 m^3/h at the time of operation.

Table 4.18. *Function and Functional Failure of Filter*

Filter				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
7.	To screens out dirt and rust particles from the fuel with size of 13 milimicron.	Primary	7.1.	Filter does not screens out dirt and rust particles from the fuel with size 13 milimicron.
			7.2.	Filters screens out dirt and rust particles from fuel with size less than 13 milimicron.

Table 4.19. *Function and Functional Failure of Main Engine Injection Pump*

Main Engine Injection Pump				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
8.	To deliver fuel into the injector with pressure of 380 bar.	Primary	8.1.	ME injection pump does not deliver fuel into the injector with pressure of 380 bar.
			8.2.	ME injection pump deliver fuel into the injector with pressure less than 380 bar.

Table 4.20. *Function and Functional Failure of Main Engine Injection Valve*

Main Engine Injection Valve				
Function			Functional Failure	
Item No.	Function Statement	Function Type	Item No.	Functional Failure Statement
9.	To spray fuel into the engine cylinders with pressure of 380 bar.	Primary	9.1.	ME injection valve does not spray fuel into the engine cylinders with pressure of 380 bar.
			9.2.	ME injection valve spray fuel into the engine cylinders with pressure less than 380 bar.

4.2.5. Failure Mode, Effects, and Criticality Analysis (FMECA)

After knowing the functional and functional failure of the fuel oil system, then the next performed Failure Mode analysis, Effects and Criticality Analysis (FMECA) using the standard ABS Guidance Notes on Reliability-Centered Maintenance. The FMECA analysis is undertaken with a bottom-up approach focusing on the possible effects of equipment failure on the system as a whole. Here are the steps taken in the FMECA analysis with the bottom-up approach :

1. Selection of components from fuel oil system as the object of research.
2. Identify the cause of failure that may occur (failure mode) of fuel oil system components.
3. Determine failure characteristics.
4. Determine the degree of impact of failure mode.
5. If the failure has a high consequence, then the identification of failure mode.
6. Determining the criticality level of failure mode using a risk assessment standard.
7. Repeat the necessary steps until all components and malfunctions have been evaluated.

4.2.5.1. Determining Failure Mode

The list of failure modes includes previous causes of failure, which may occur and overall possible causes of failure that are not taken into account. In this final project, failure mode is obtained from several sources including :

1. Historical repair data from MV Kendari I
2. Maintenance plan from MV Kendari I
3. OREDA 2002

4.2.5.2. Determining Failure Effects

In the identification of failure effects should be done three stages namely :

1. Local effects on the system or component being analyzed should include methods of detecting failures such as alarm or indicator tests, decreasing component performance levels, and ensuring that there are systems with the same functionality as stand-by. In this final project, the determination of local effects is obtained from interview with company's collaborator and other required literature.
2. Subsequent effects caused to the system must include potential damage to equipment or systems, and damage to other equipment both in the system and outside the system.
3. End effects of component failures will include potential threats to safety and the environment, the operational effectiveness of the vessel as well as the downtime required to repair the damage.

4.2.5.3. Determining Level of Criticality

In determining the level of consequence, frequency and risk matrix on FMECA analysis using RCM ABS Rules standard, standard used has been presented in Section 6 of ABS Guidance Notes on Reliability-Centered Maintenance. In accordance with **Section 2.11.6.5.** and **2.11.6.6.** in analyzing the criticality level of each failure mode that occurs on the components required some classification used include classification of functional group, definition of severity level and current likelihood.

Based on **Appendix 3**, the classification and definition of each level of consequences caused due to component failure occur. From the classification data, then used as a reference in the FMECA analysis as the criticality of any failure modesang occur. Further defined the definition of probability of occurence as presented in **Table 2.5.**

After performing the identification of severity and likelihood, then the conversion to the risk matrix according to **Table 2.6.** If the whole analysis has been completed, then the result of FMECA analysis can be presented in **Appendix 4.**

4.2.6. Selection of The Failure Management Tasks

If the FMECA analysis has been completed, then the next stage is the analysis of maintenance task allocation and planning. Based on **Table 2.9.** this stage identifies the failure mode in the case of the type of failure (hidden or evident failure) and the proposed actions of each failure mode.

4.2.6.1. Hidden or Evident Failure

As explained in **Section 2.11.7.3.** hidden or evident failure will explain that the failure has a direct or indirect effect on system performance. From the results of maintenance task allocation and planning analysis in **Appendix 5** then obtained the type of failure level as presented in **Figure 4.3.**

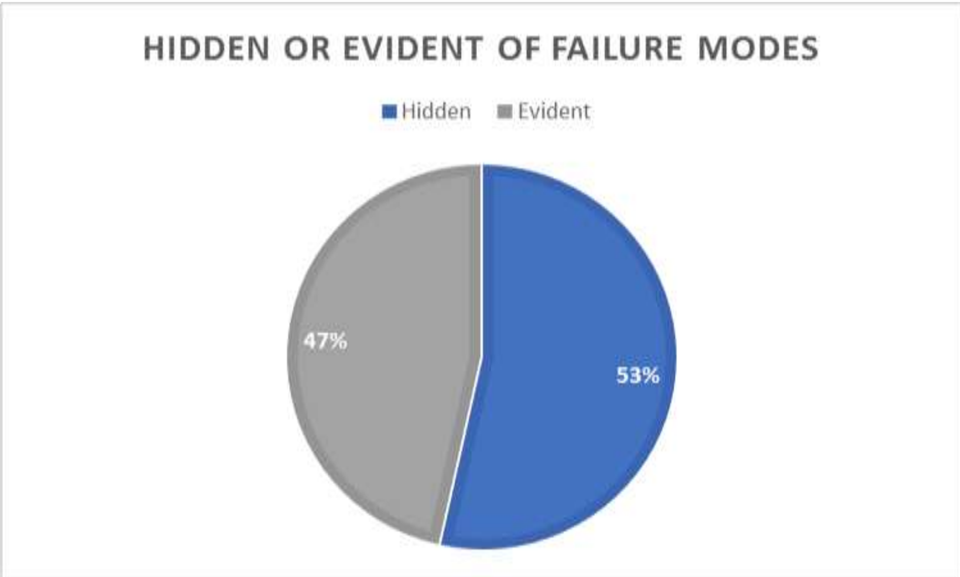

Figure 4.3. *Percentage of Hidden or Evident Failure Mode*

Based on **Figure 4.3.** identified 53.48% of the overall failure mode has a type of hidden failure, while 46.51% identified as evident failure. Based on these results, the company will be recommended to identify and perform further maintenance of the failure mode in accordance with the proposed actions to be identified at a next stage. This is because the type of evident failure mode can increase the consequences of the impact caused by any failure that occurs on the performance as well as the system as a whole.

4.2.6.2. Proposed Actions

The purpose of this analysis is to determine the proposed actions necessary to identify or correct the failure that occurs based on predetermined standards. The proposed actions analysis at this stage refers to the steps described in **Section 2.11.7.** In this final project proposed actions using ABS Rules standard and logic tree analysis in the standard. In addition to determining the proposed actions of a failure mode required supporting data such as paper, historical repair data that has been previously documented and interview with company's collaborator. The result of identification of proposed actions is presented in **Appendix 5**.

Furthermore, based on the results of maintenance task allocation and planning analysis, will be summed up into a summary of maintenance task. In this stage every failure mode that has been done maintenance action identification, then will do the task selection. Task selection is done to determine the action or decision of the applied maintenance is the right type of maintenance (task type), effective and efficient. Selection of the right type of maintenance uses the stages described from the logic tree analysis used. So it is expected with the selection of the right type of maintenance, then the maintenance recommendations are also running well.

Effective means that the maintenance actions performed are expected to be able to detect the failure that occurred or find a hidden failure. So that in its operation, failure can be prevented and overcome well. Efficient means that maintenance actions performed have economic value or have a profit value when viewed from the comparison of total maintenance costs with repair costs.

Each recommended maintenance action to overcome the failure mode that occurs in the FMECA analysis will be divided into several categories. Categorization of these are the types of maintenance that is preventive maintenance (PM), condition monitoring (CM), failure finding (FF), and one-time change (OTC). Stages in categorizing maintenance types based on logic tree analysis in ABS Guidance Notes on Reliability-Centered Maintenance. The logic tree analysis result and the result of the analysis on the summary stage of maintenance task are presented in **Appendix 6**. While the result of the analysis using logic tree analysis is presented in **Appendix 7**. The following is the result of the summary of maintenance task stage shown in **Table 4.21.**

Table 4.21. *Recapitulation on Summary of Maintenance Task*

Percentage of Maintenance Category		
Maintenance Category	Failure Mode	
	Amount	Percentage (%)
A	43	100%
Number of Tasklist	43	100%

As explained in **Section 2.11.8.** that each maintenance task performed (tasklist) is categorized into three categories based on parties, procedures, and where the maintenance action is done. Based on **Table 4.21.** presented that all failure modes enter in category A with 100% percentage of 43 tasklists. Category A is a tasklist category where every maintenance action is allowed to be directly done by the ship maintenance officer or the crew of the ship itself.

Category A has the highest percentage because most of the recommended maintenance actions to be performed can be done on the spot by the vessel crew without the need to be accompanied by surveyors, vendors, complex equipment or dry dock facility. In addition, the action included in category A is a maintenance activity carried out periodically and continuously throughout the ship in operation. So this is the duty and responsibility of the owner ship where in this case done by the crew of the ship itself.

In the summary stage of maintenance task, every action maintenance (tasklist) is done to determine the appropriate type of maintenance (task type). Each tasklist is categorized into each type of maintenance based on logic tree analysis in the ABS Guidance Notes on Reliabiklity-Centered Maintenance. The following is the result of determining the type of maintenance (task type) from the summary stage of maintenance task shown in **Table 4.22.**

Table 4.22. *Recapitulation of Task Type on Each Maintenance Category*

Maintenance Category A		
Task Type	Amount	Percentage (%)
Preventive Maintenance (PM)	18	41,8%
Condition Monitoring (CM)	13	30,2%
Failure Finding (FF)	12	27,9%
One-Time Change (OTC)	0	0%
Number of Tasklist	43	100%

4.3. Quantitative Analysis

Quantitative analysis is done by using software Reliasoft Weibull++ Version 6 from the historical data damage to the fuel oil system. This analysis is used to obtain the most appropriate distribution and parameters for TTF (Time to Failure) data. Distribution and parameters are used to find failure rate function and reliability function.

4.3.1. Quantitative Analysis HFO Transfer Pump

In detail the stages of systematic data processing have been described in **Section 3.5.** For example, the following **Table 4.23.** is the result of processing TTF (Time to Failure) and MTTF (Mean Time to Failure) for the HFO Transfer Pump component.

Table 4.23. *Maintenance Data of HFO Transfer Pump*

Start Date	Completion Date	TTF (Hours)
12/01/2011	12/01/2011	0
25/08/2011	25/08/2011	4000
5/07/2012	5/07/2012	6000
10/01/2014	10/01/2014	10000
22/10/2014	22/10/2014	5000
9/03/2015	9/03/2015	9000
6/01/2017	6/01/2017	12000
Amount		46000
Average		6600

Furthermore, from the results of processing with Reliasoft Weibull++ Version 6 software obtained the pattern of TTF data distribution from the HFO transfer pump following the weibull 2 distribution, where the Beta (β) parameter is 2,5192 and the Eta (η) is 8679,584. **Table 4.24.** below is an example of reliability data processing on a HFO transfer pump using a time interval of every 500 hours added, processed with Ms. Excel. The reliability formula is included in column R(t) adjusted for its distribution. Further to the failure rate formula also use the same way.

Table 4.24. *Reliability Data of HFO Transfer Pump*

Reliability			
Weibul II		From TTF	
t(hours)	R(t)	Beta (β)	Eta (η)
0,001	1	2,5192	8679,5840
500	0,9992463	2,5192	8679,5840
1000	0,9956868	2,5192	8679,5840
1500	0,9880673	2,5192	8679,5840
2000	0,9755252	2,5192	8679,5840
2500	0,957458	2,5192	8679,5840
3000	0,9334972	2,5192	8679,5840
3500	0,9035057	2,5192	8679,5840
4000	0,8675774	2,5192	8679,5840
4500	0,8260333	2,5192	8679,5840
5000	0,7794103	2,5192	8679,5840

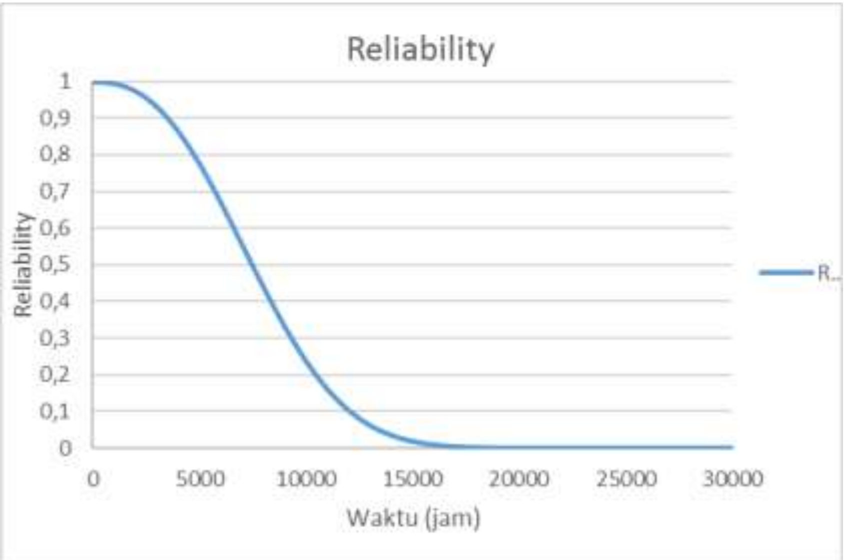

Figure 4.4. *Reliability Graph of HFO Transfer Pump*

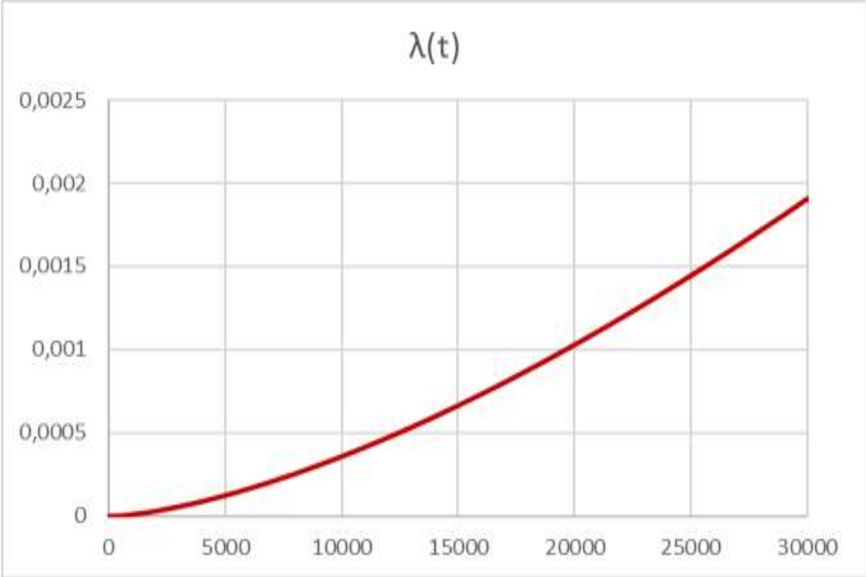

Figure 4.5. *Failure Rate Graph of HFO Transfer Pump*

Figure 4.5. above is a graph of failure rates for HFO Transfer Pump. Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on HFO transfer pump.

4.3.2. Quantitative Analysis MDO Transfer Pump

Using the same stages in **Section 3.5.** other component quantitative data is processed to obtain important parameters. The pattern of TTF data distribution from the MDO transfer pump following the weibull 2 distribution, where the Beta (β) parameter is 2,3424 and the Eta (η) is 8739,709. **Figure 4.6.** below is a graph of reliability of MDO transfer pump.

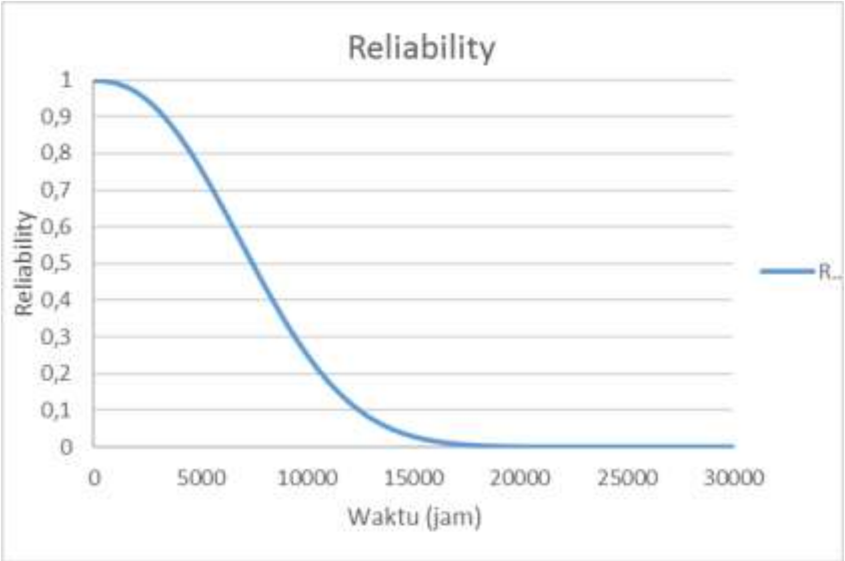

Figure 4.6. *Reliability Graph of MDO Transfer Pump*

Then the failure rate graph for the MDO transfer pump is shown in **Figure 4.7.** below.

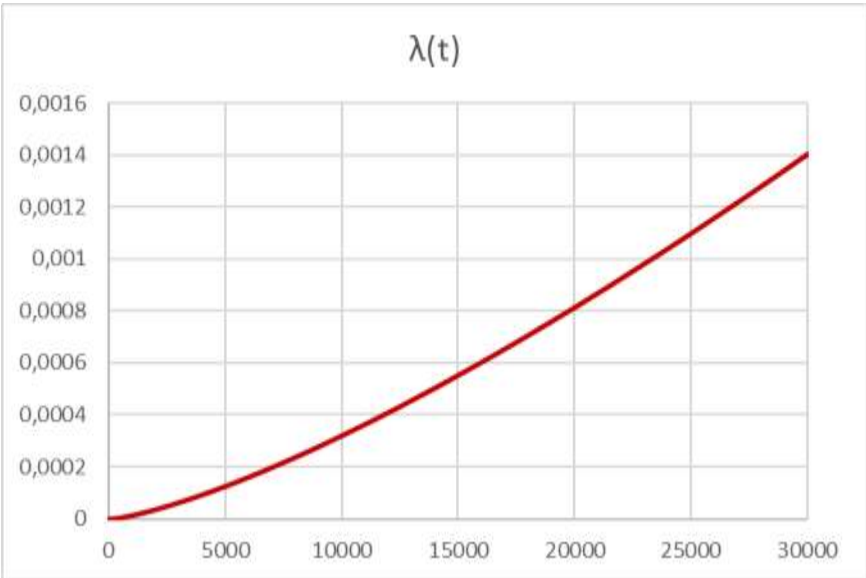

Figure 4.7. *Failure Rate Graph of MDO Transfer Pump*

Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on MDO transfer pump.

4.3.3. Quantitative Analysis Separator

The pattern of TTF data distribution from the Separator following the normal distribution, where the Mean (μ) parameter is 2300 and the Std (σ) is 272,4725. **Figure 4.8.** below is a graph of reliability of Separator.

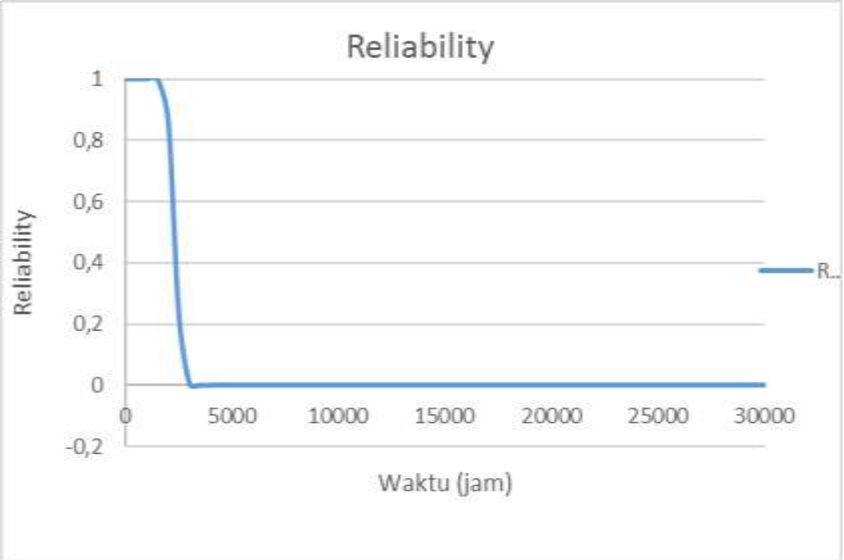

Figure 4.8. *Reliability Graph of Separator*

Then the failure rate graph for the Separator is shown in **Figure 4.9.** below.

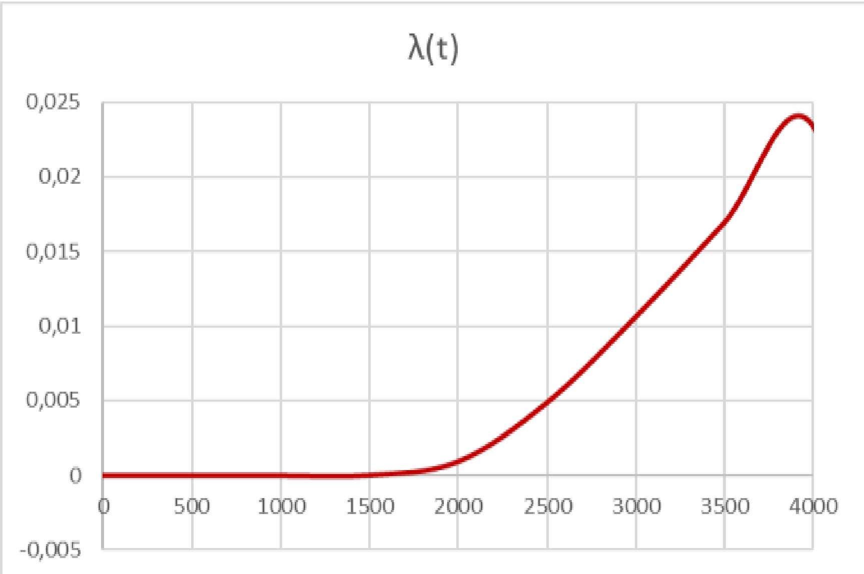

Figure 4.9. *Failure Rate Graph of Separator*

Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on Separator.

4.3.4. Quantitative Analysis Heater

The pattern of TTF data distribution from the Heater following the lognormal distribution, where the Mean (μ) parameter is 8,9314 and the Std (σ) is 0,1974. **Figure 4.10.** below is a graph of reliability of Heater.

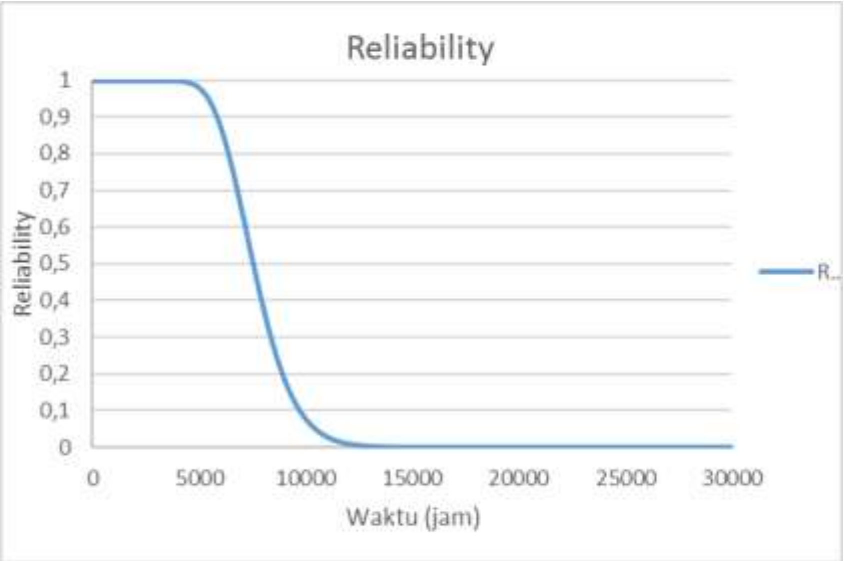

Figure 4.10. *Reliability Graph of Heater*

Then the failure rate graph for the Heater is shown in **Figure 4.11.** below.

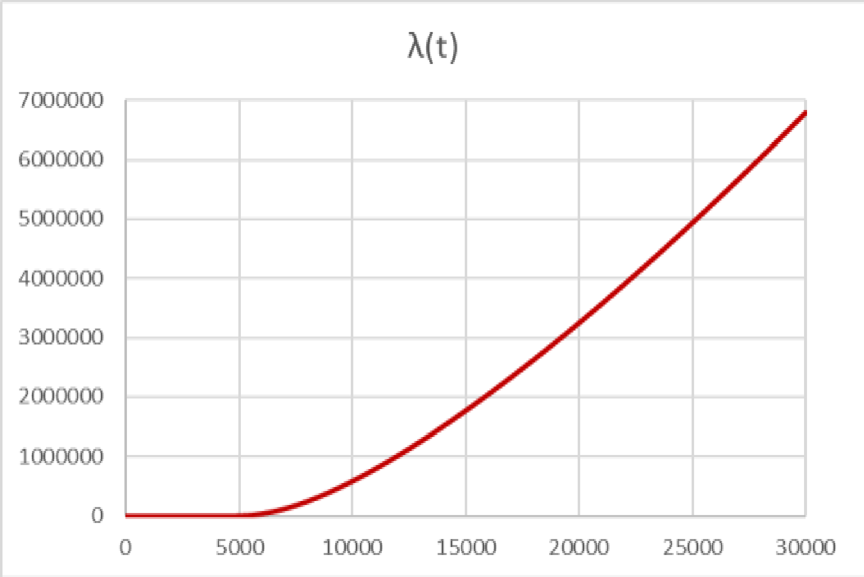

Figure 4.11. *Failure Rate Graph of Heater*

Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on Heater.

4.3.5. Quantitative Analysis HFO Feeder Pump

The pattern of TTF data distribution from the HFO feeder pump following the weibull 2 distribution, where the Beta (β) parameter is 2,4773 and the Eta (η) is 8702,0273. **Figure 4.12.** below is a graph of reliability of HFO feeder pump.

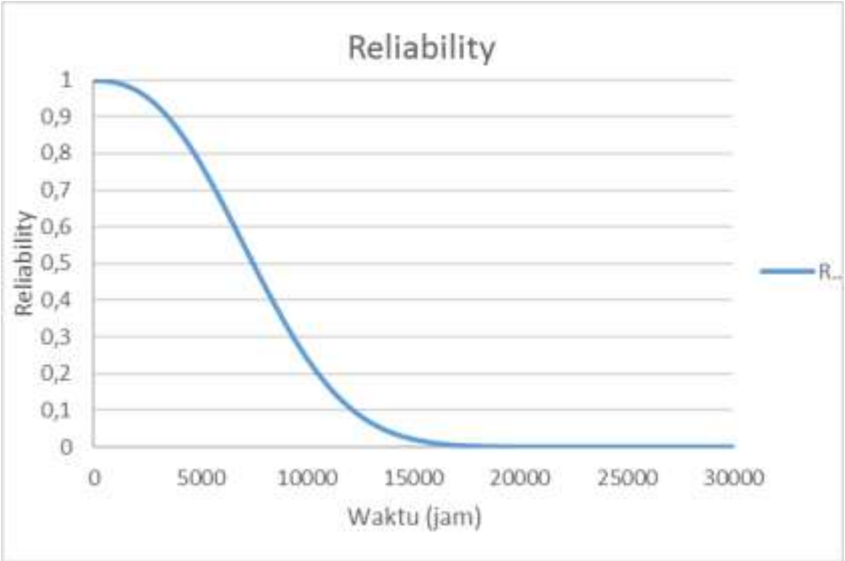

Figure 4.12. *Reliability Graph of HFO Feeder Pump*

Then the failure rate graph for the HFO feeder pump is shown in **Figure 4.13.** below.

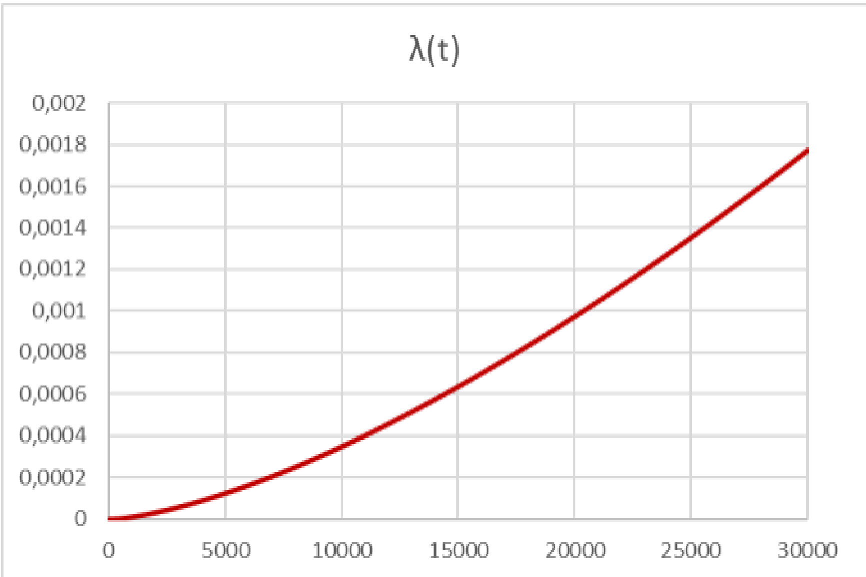

Figure 4.13. *Failure Rate Graph of HFO Feeder Pump*

Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on HFO feeder pump.

4.3.6. Quantitative Analysis HFO Circulating Pump

The pattern of TTF data distribution from the HFO circulating pump following the weibull 2 distribution, where the Beta (β) parameter is 2,5192 and the Eta (η) is 8679,5841. **Figure 4.14.** below is a graph of reliability of HFO circulating pump.

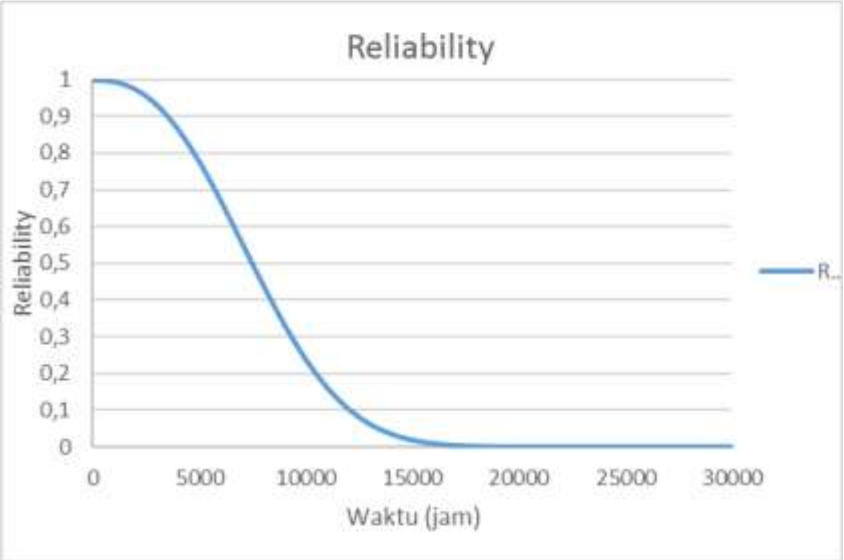

Figure 4.14. *Reliability Graph of HFO Circulating Pump*

Then the failure rate graph for the HFO circulating pump is shown in **Figure 4.15.** below.

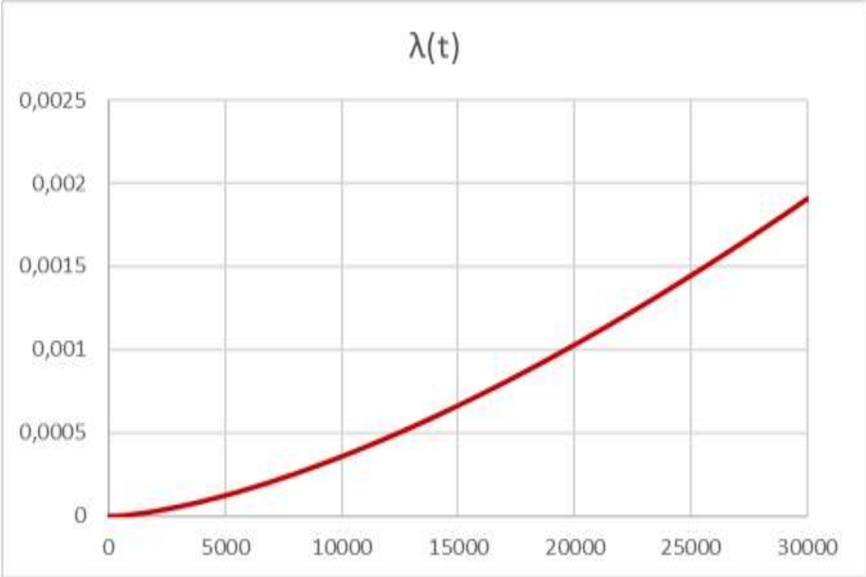

Figure 4.15. *Failure Rate Graph of HFO Circulating Pump*

Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on HFO circulating pump.

4.3.7. Quantitative Analysis Filter

The pattern of TTF data distribution from the Filter following the lognormal distribution, where the Mean (μ) parameter is 8,9136 and the Std (σ) is 0,1567. **Figure 4.16.** below is a graph of reliability of Filter.

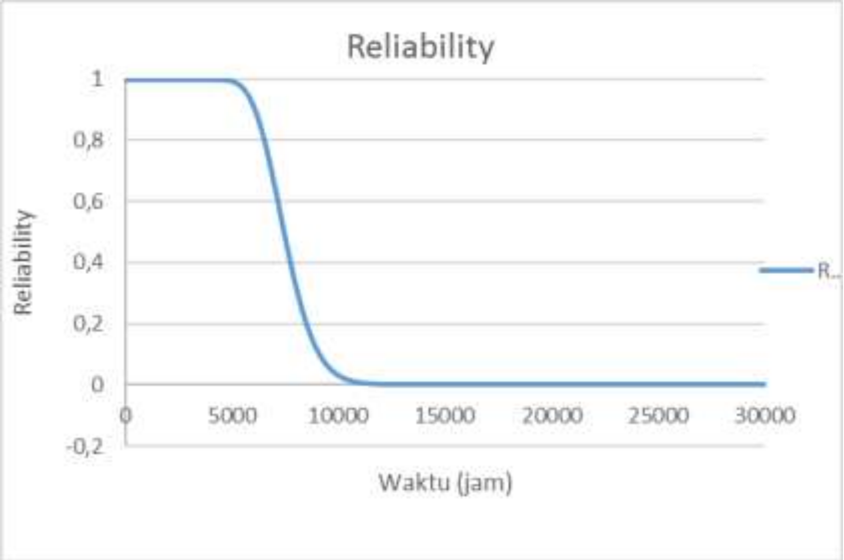

Figure 4.16. *Reliability Graph of Filter*

Then the failure rate graph for the Filter is shown in **Figure 4.17.** below.

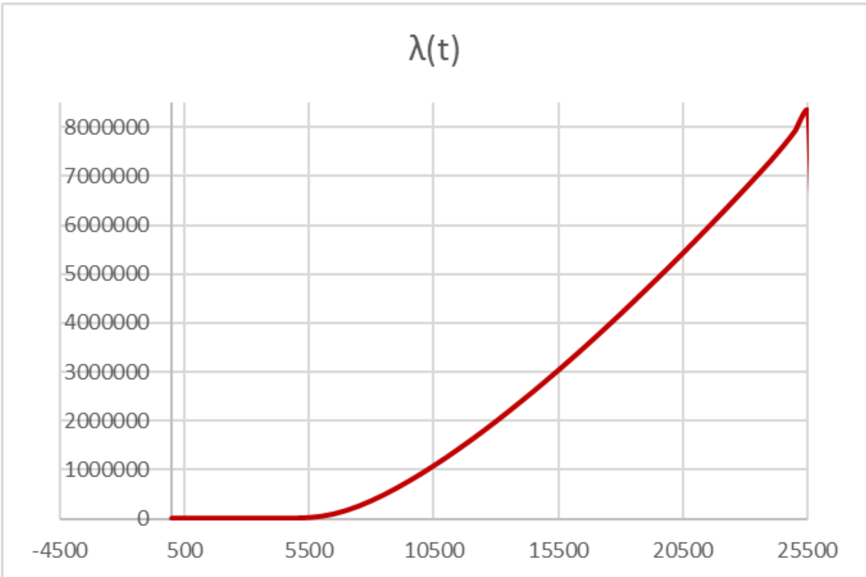

Figure 4.17. *Failure Rate Graph of Filter*

Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on Filter.

4.3.8. Quantitative Analysis ME Injection Pump

The pattern of TTF data distribution from the ME injection pump following the normal distribution, where the Mean (μ) parameter is 3500,0001 and the Std (σ) is 659,5365. **Figure 4.18.** below is a graph of reliability of ME injection pump.

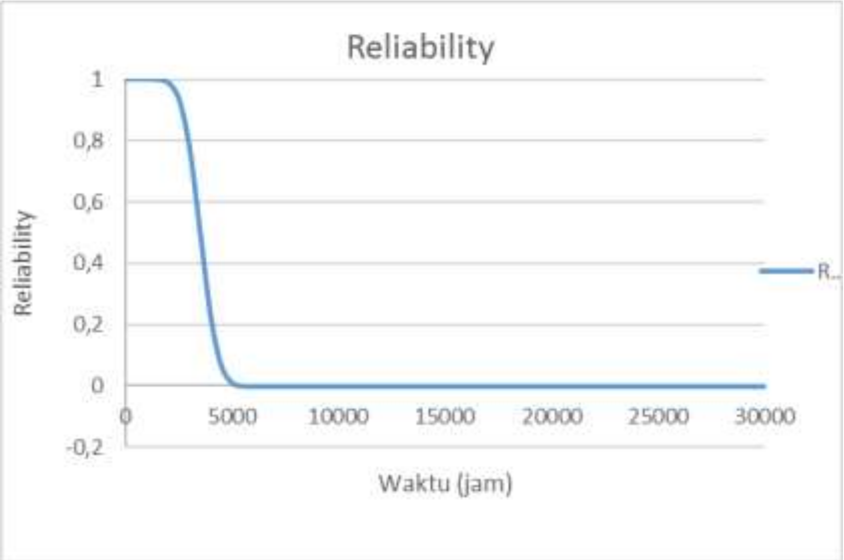

Figure 4.18. *Reliability Graph of ME Injection Pump*

Then the failure rate graph for the ME injection pump is shown in **Figure 4.19.** below.

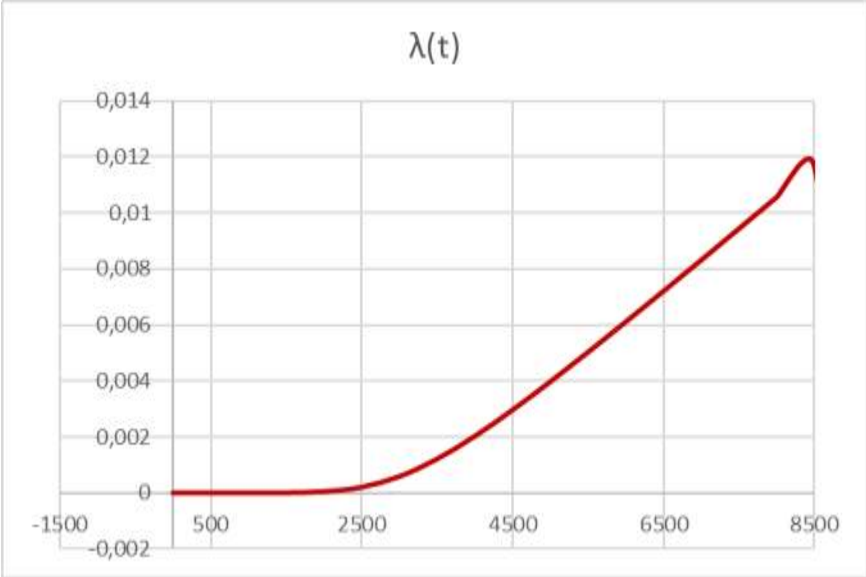

Figure 4.19. *Failure Rate Graph of ME Injection Pump*

Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on ME injection pump.

4.3.9. Quantitative Analysis ME Injection Valve

The pattern of TTF data distribution from the ME injection valve following the weibull 2 distribution, where the Beta (β) parameter is 3,5654 and the Eta (η) is 4038,3579. **Figure 4.20.** below is a graph of reliability of ME injection valve.

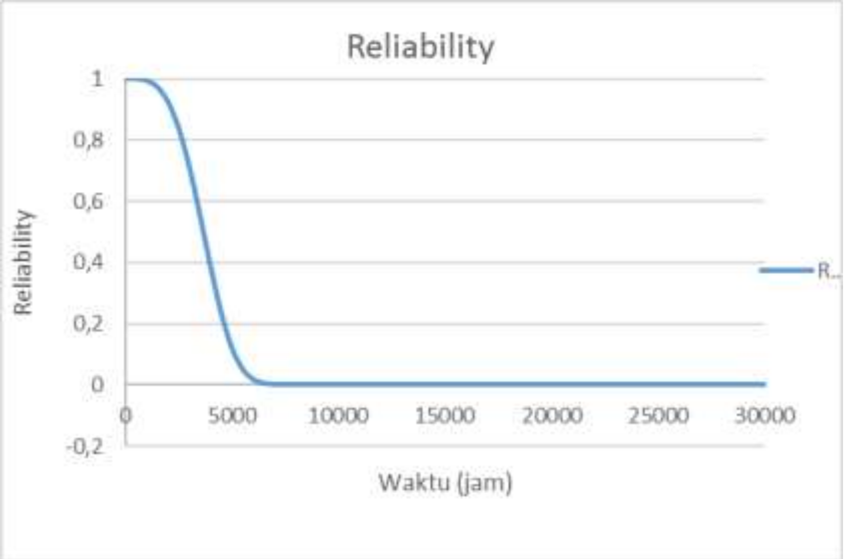

Figure 4.20. *Reliability Graph of ME Injection Valve*

Then the failure rate graph for the ME injection valve is shown in **Figure 4.21.** below.

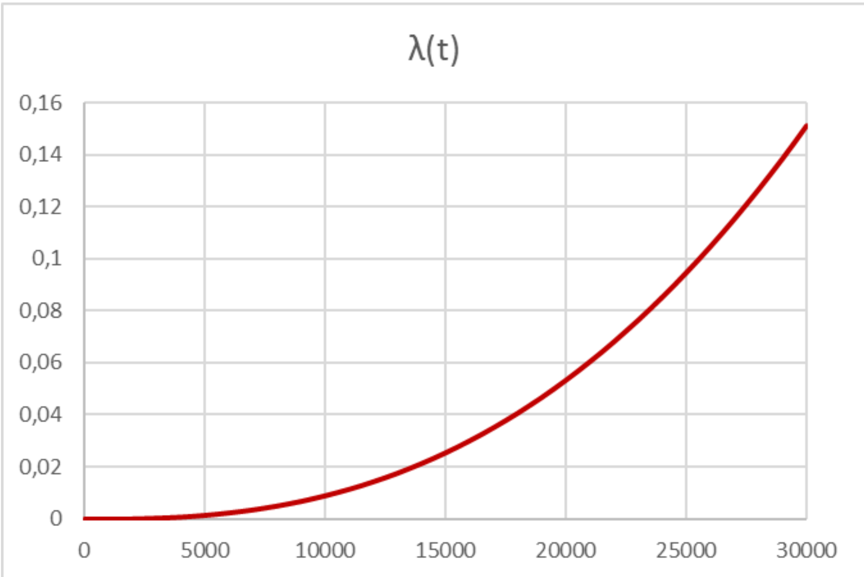

Figure 4.21. *Failure Rate Graph of ME Injection Valve*

Based on the graph, it can be seen that the failure rate is increasing failure rate, which in this case means the optimal preventive maintenance action to be performed on ME injection valve.

4.4. Schedule and Maintenance Cost Analysis

To analyze the schedule with optimum maintenance cost can be calculated by the formula already described in **Section 2.12.**

4.4.1. HFO Transfer Pump

After doing calculation Tc(tp), then the total cost graph for the HFO transfer pump is shown in **Figure 4.22.** below.

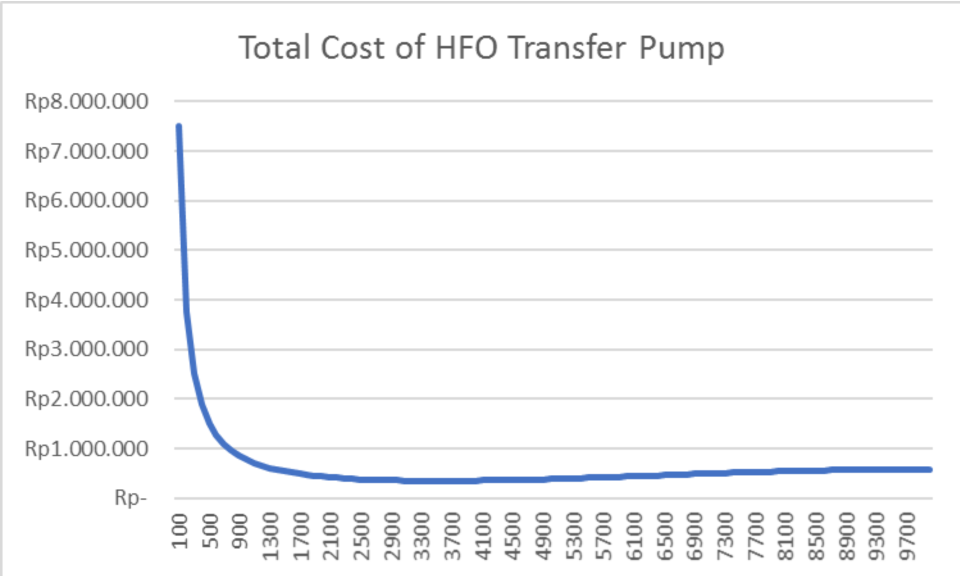

Figure 4.22. *Total Cost Graph of HFO Transfer Pump*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.22.** it can be seen that there is a turning point when tp is worth 3500 hours with minimum estimated cost of Rp. 346.017,00.

When compared with schedule existing maintenance with the same modeling where HFO transfer pump maintenance at intervals of 12000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 3500 hours the total cost is much cheaper. Based on **Figure 4.23.** it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

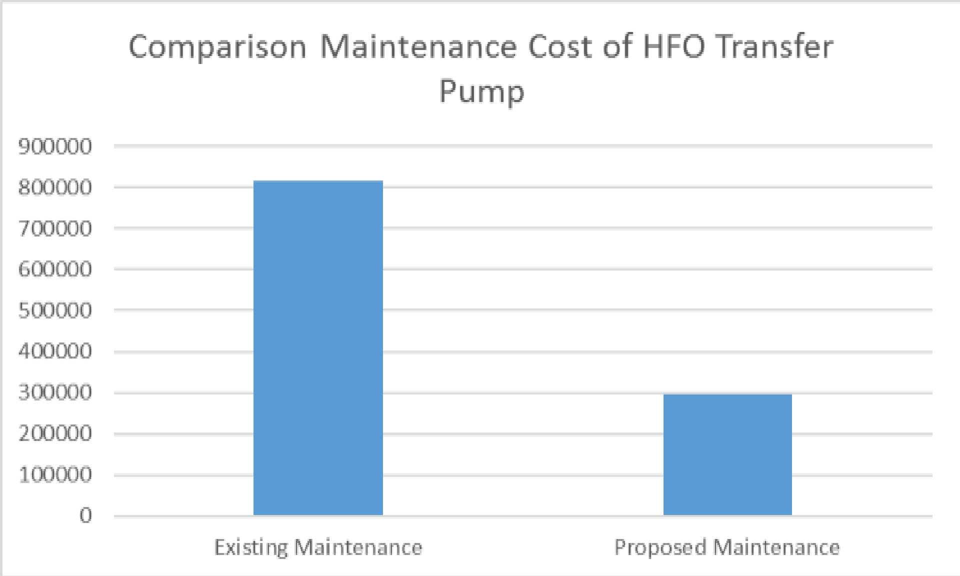

Figure 4.23. *Comparison Maintenance Cost of HFO Transfer Pump*

4.4.2. MDO Transfer Pump

After doing calculation Tc(tp), then the total cost graph for the MDO transfer pump is shown in **Figure 4.24.** below.

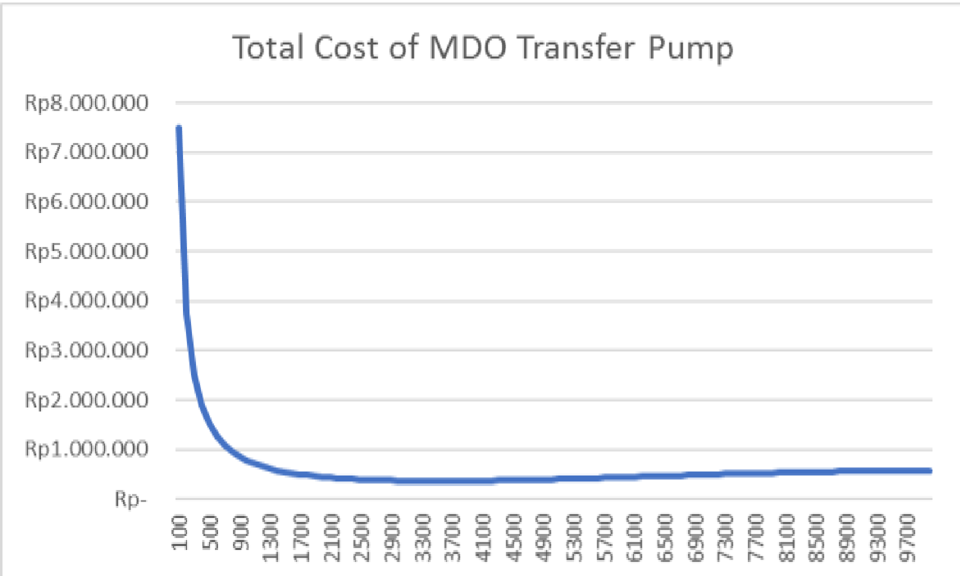

Figure 4.24. *Total Cost Graph of MDO Transfer Pump*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.24.** it can be seen that there is a turning point when tp is worth 3500 hours with minimum estimated cost of Rp. 363.019,00.

When compared with schedule existing maintenance with the same modeling where MDO transfer pump maintenance at intervals of 12000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 3500 hours the total cost is much cheaper. Based on **Figure 4.25.** it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

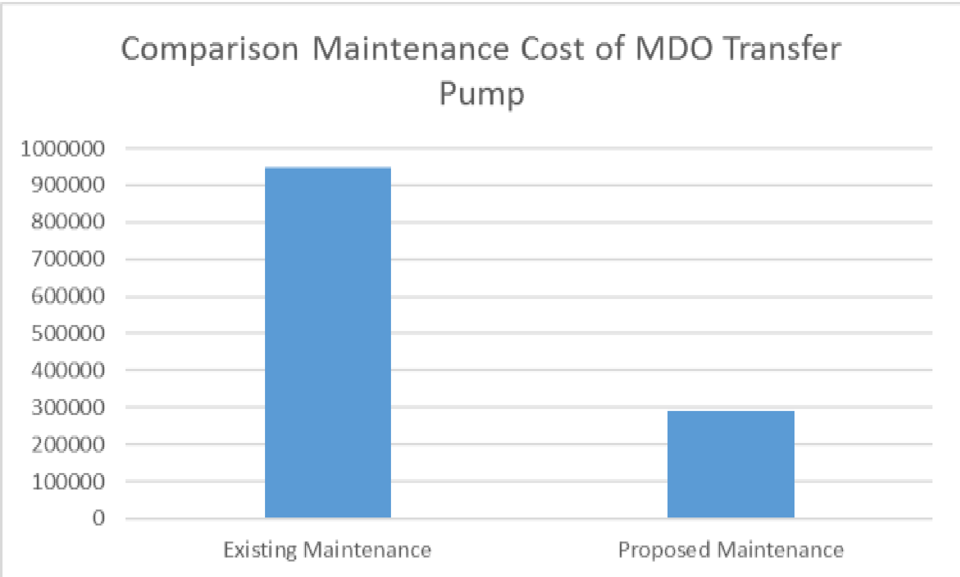

Figure 4.25. *Comparison Maintenance Cost of MDO Transfer Pump*

4.4.3. Separator

After doing calculation Tc(tp), then the total cost graph for the Separator is shown in **Figure 4.26.** below.

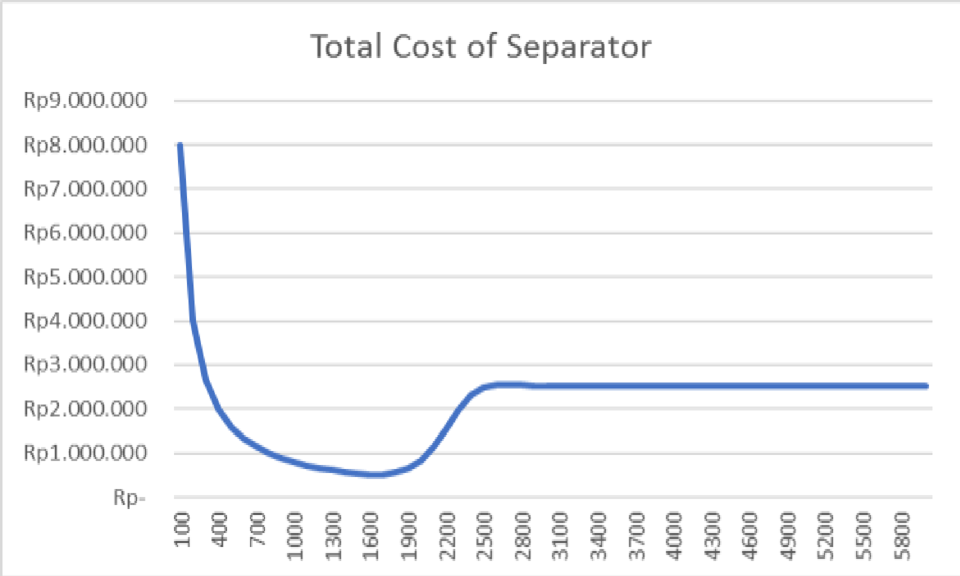

Figure 4.26. *Total Cost Graph of Separator*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.26.** it can be seen that there is a turning point when tp is worth 1700 hours with minimum estimated cost of Rp. 518.342,00.

When compared with schedule existing maintenance with the same modeling where Separator maintenance at intervals of 2000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 1700 hours the total cost is much cheaper. Based on **Figure 4.27.** it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

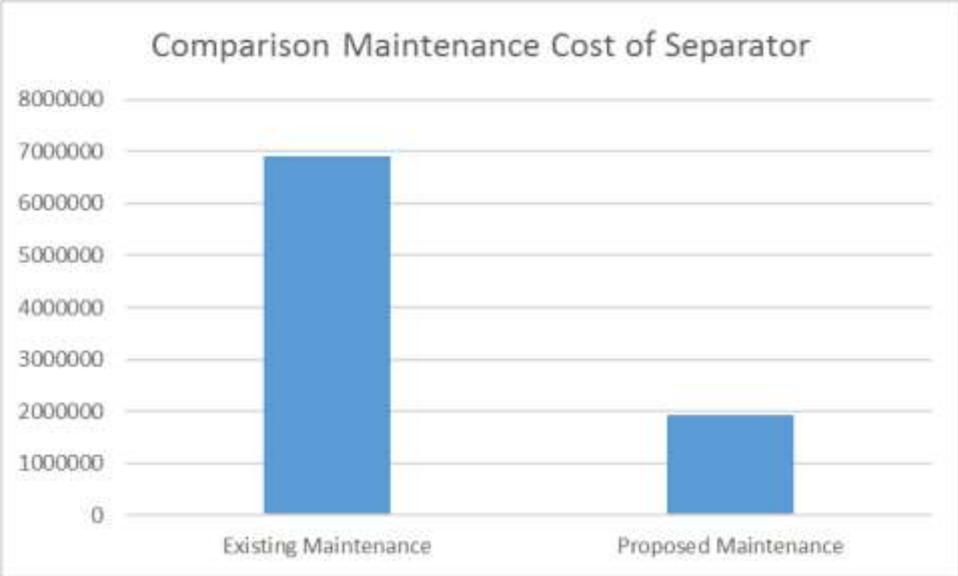

Figure 4.27. *Comparison Maintenance Cost of Separator*

4.4.4. Heater

After doing calculation Tc(tp), then the total cost graph for the Heater is shown in **Figure 4.28.** below.

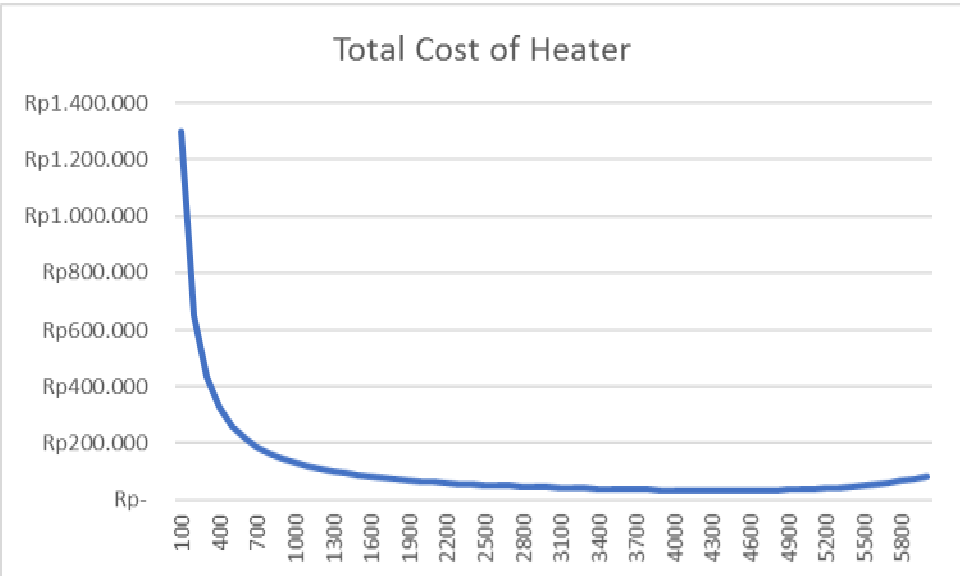

Figure 4.28. *Total Cost Graph of Heater*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.28.** it can be seen that there is a turning point when tp is worth 4400 hours with minimum estimated cost of Rp. 31.354,00.

When compared with schedule existing maintenance with the same modeling where Heater maintenance at intervals of 2000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 4400 hours the total cost is a little cheaper. Based on **Figure 4.29.** it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

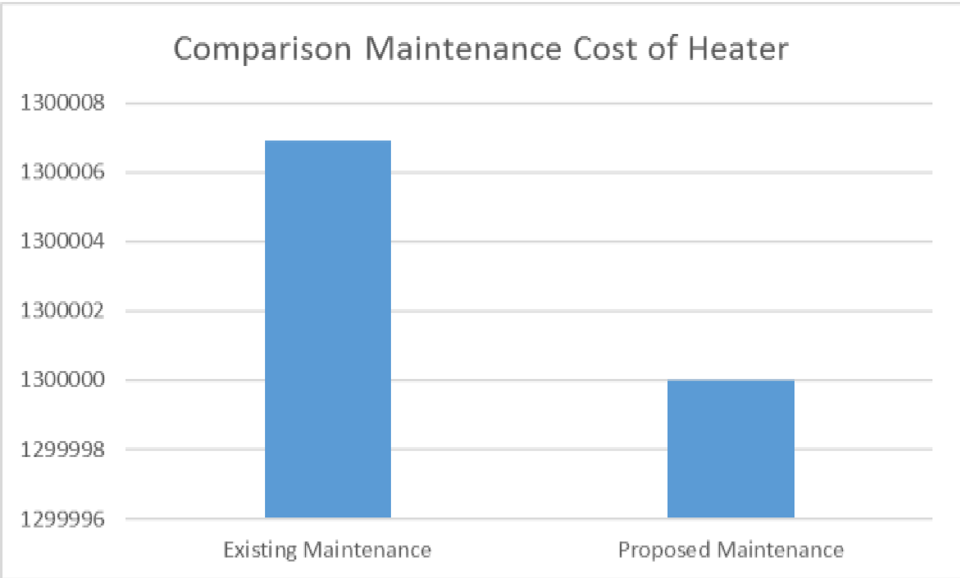

Figure 4.29. *Comparison Maintenance Cost of Heater*

4.4.5. HFO Feeder Pump

After doing calculation Tc(tp), then the total cost graph for the HFO feeder pump is shown in **Figure 4.30.** below.

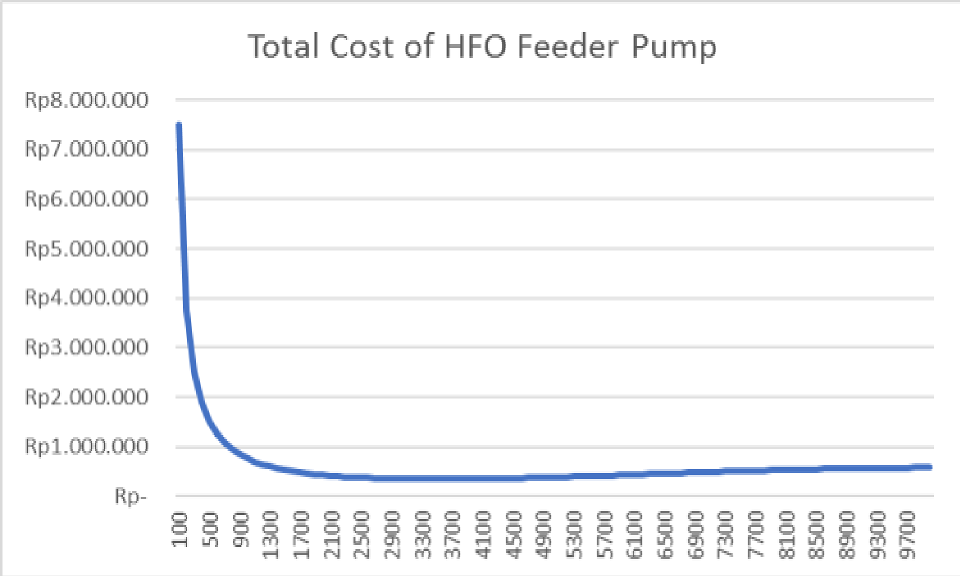

Figure 4.30. *Total Cost Graph of HFO Feeder Pump*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.30.** it can be seen that there is a turning point when tp is worth 3500 hours with minimum estimated cost of Rp. 350.380,00.

When compared with schedule existing maintenance with the same modeling where HFO feeder pump maintenance at intervals of 12000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 3500 hours the total cost is much cheaper. Based on **Figure 4.31.** it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

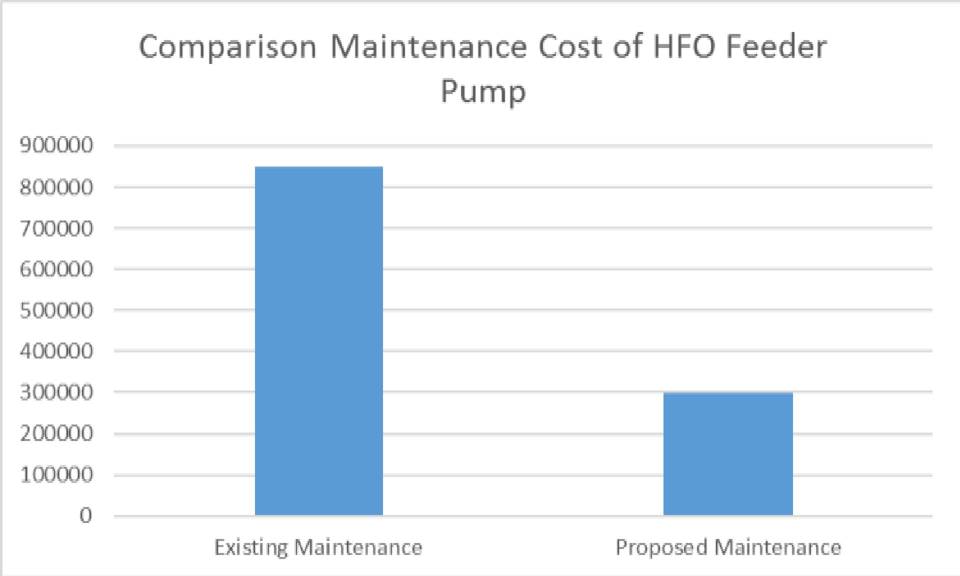

Figure 4.31. *Comparison Maintenance Cost of HFO Feeder Pump*

4.4.6. HFO Circulating Pump

After doing calculation Tc(tp), then the total cost graph for the HFO circulating pump is shown in **Figure 4.32.** below.

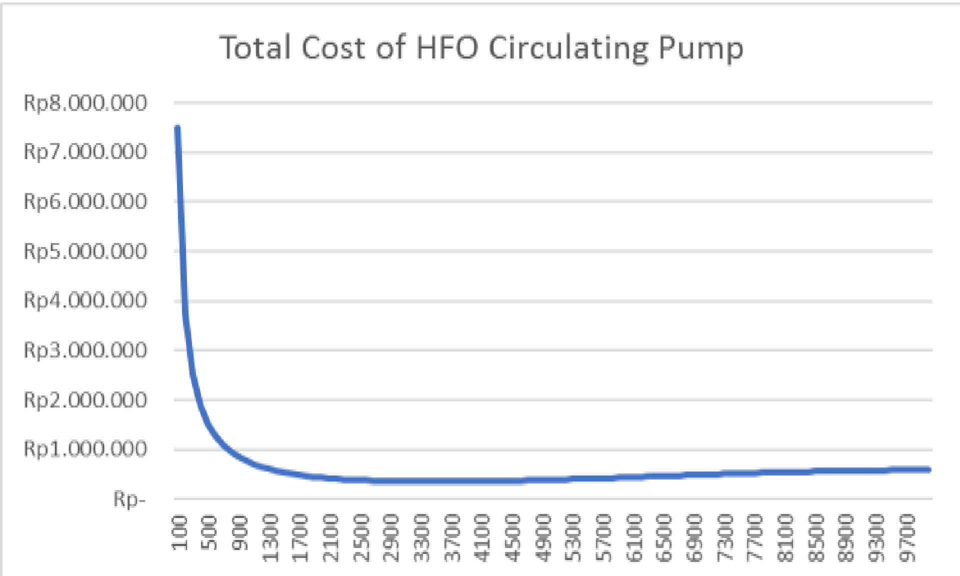

Figure 4.32. *Total Cost Graph of HFO Circulating Pump*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.32.** it can be seen that there is a turning point when tp is worth 3500 hours with minimum estimated cost of Rp. 346.017,00.

When compared with schedule existing maintenance with the same modeling where HFO circulating pump maintenance at intervals of 12000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 3500 hours the total cost is much cheaper. Based on **Figure 4.33.** it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

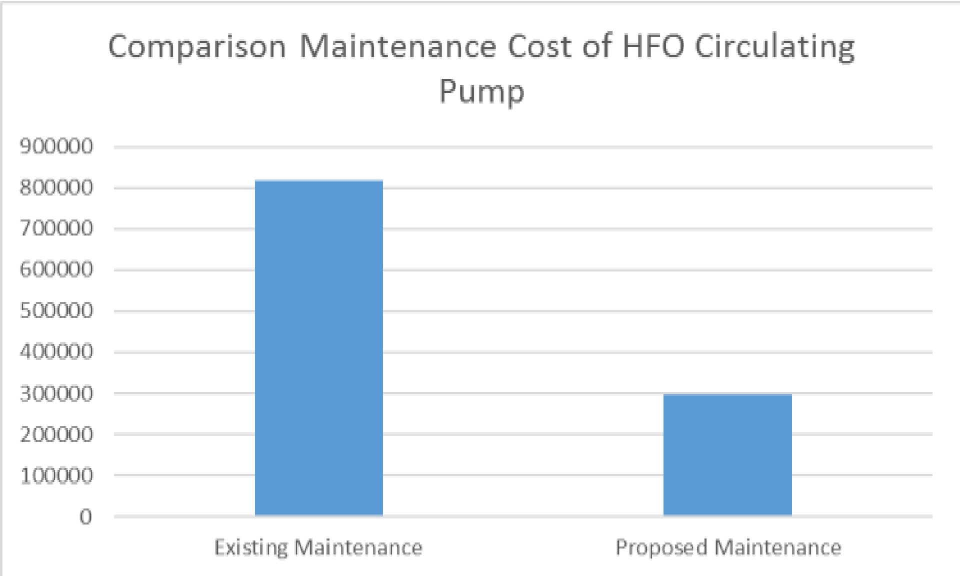

***Figure 4.33.** Comparison Maintenance Cost of HFO Circulating Pump*

4.4.7. Filter

After doing calculation Tc(tp), then the total cost graph for the Filter is shown in **Figure 4.34.** below.

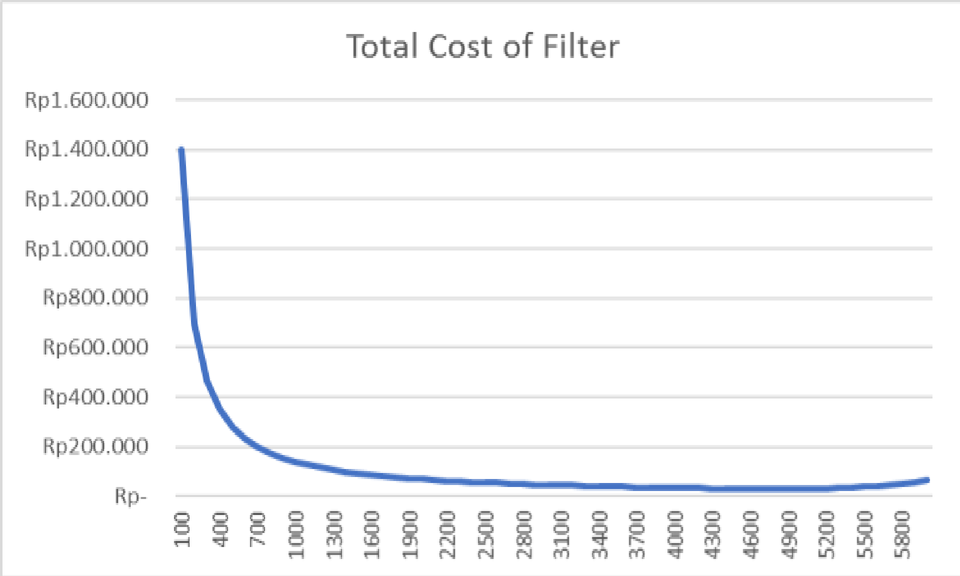

Figure 4.34. *Total Cost Graph of Filter*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.34.** it can be seen that there is a turning point when tp is worth 4800 hours with minimum estimated cost of Rp. 30.619,00.

When compared with schedule existing maintenance with the same modeling where Filter maintenance at intervals of 5000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 4800 hours the total cost is a little cheaper. Based on **Figure 4.35.** it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

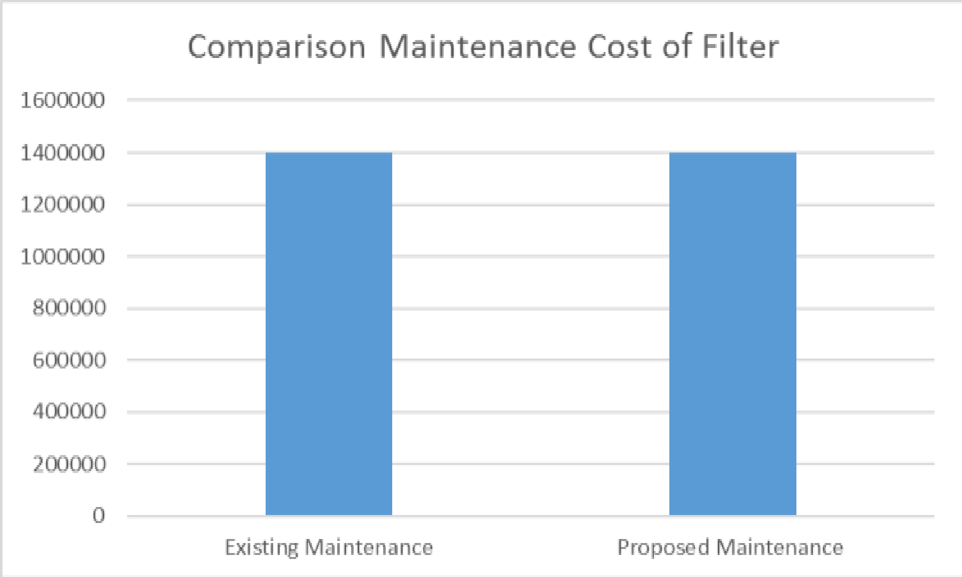

Figure 4.35. *Comparison Maintenance Cost of Filter*

4.4.8. ME Injection Pump

After doing calculation Tc(tp), then the total cost graph for the ME injection pump is shown in **Figure 4.36.** below.

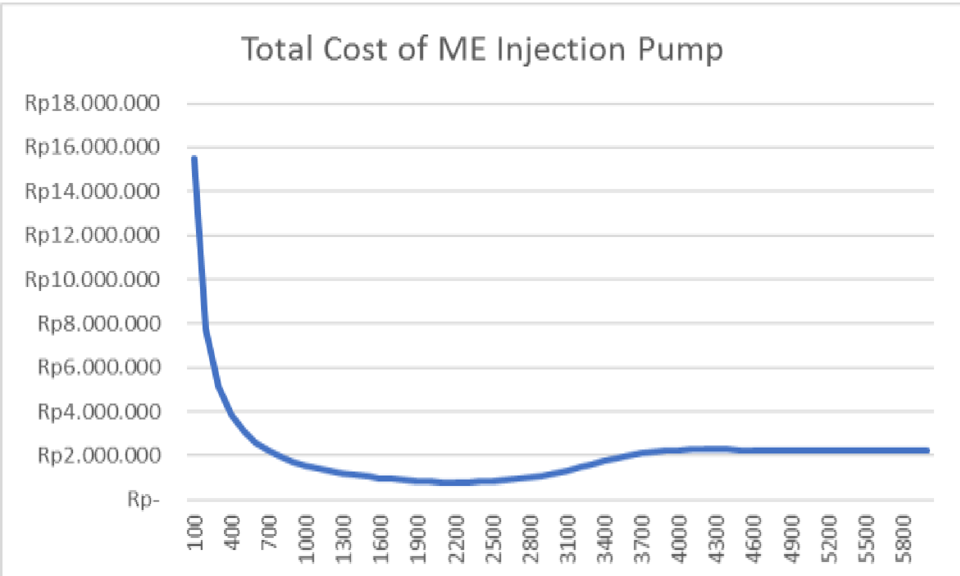

Figure 4.36. *Total Cost Graph of ME Injection Pump*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.36.** it can be seen that there is a turning point when tp is worth 2200 hours with minimum estimated cost of Rp. 792.632,00.

When compared with schedule existing maintenance with the same modeling where ME injection pump maintenance at intervals of 5000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 2200 hours the total cost is a little cheaper. Based on **Figure 4.37.** it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

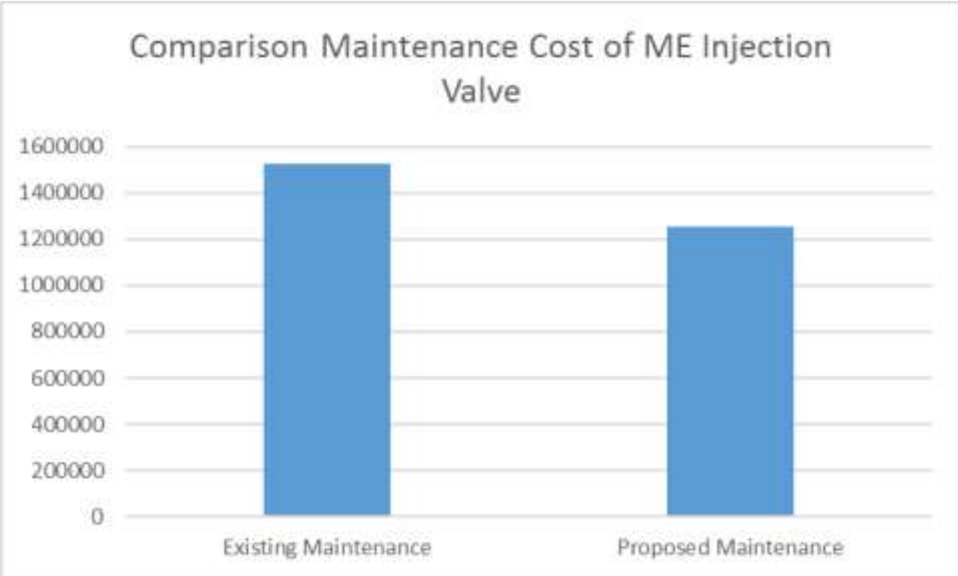

Figure 4.37. *Comparison Maintenance Cost of ME Injection Pump*

4.4.9. Main Engine Injection Valve

After doing calculation Tc(tp), then the total cost graph for the ME injection valve is shown in **Figure 4.38.** below.

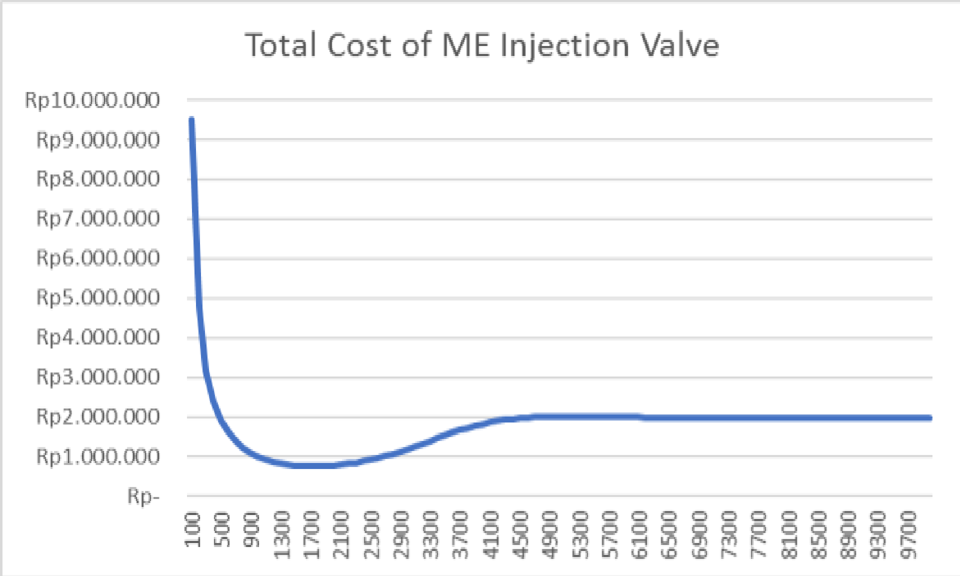

Figure 4.38. *Total Cost Graph of ME Injection Valve*

Minimum cost estimation value is obtained by looking for turning point on a curve. Based on **Figure 4.38.** it can be seen that there is a turning point when tp is worth 1700 hours with minimum estimated cost of Rp. 755.806,00.

When compared with schedule existing maintenance with the same modeling where ME injection valve maintenance at intervals of 5000 hours then the proposed maintenance is more advantageous because if the component is maintenance at intervals of 1700 hours the total cost is a little cheaper. Based on **Figure 4.39**. it can be seen that comparison maintenance cost between proposed maintenance and existing maintenance.

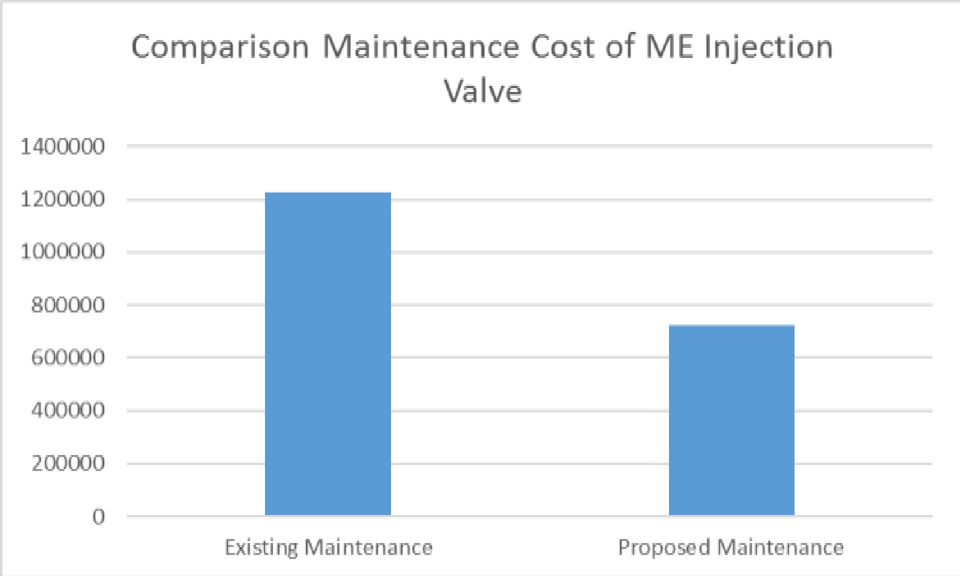

Figure 4.39. *Comparison Maintenance Cost of ME Injection Valve*

After performing the calculation of total cost on each component then made a summary of maintenance cost planning for 5 years according to **Table 4.25.** Since each component has a different rate of failure, each component has different maintenance intervals as well.

Table 4.25. *Summary Maintenance Cost on Fuel Oil System for 5 years*

No.	Component	Interval Between Maintenance	Reliability Value	Maintenance Cost
1	HFO Transfer Pump	3500	0,90350573	Rp 2.847.227,66
2	MDO Transfer Pump	3500	0,889374919	Rp 2.987.128,56
3	Separator	1700	0,986169362	Rp 8.781.323,29
4	Heater	4400	0,99698272	Rp 2.052.271,83
5	HFO Feeder Pump	3500	0,900561792	Rp 2.883.129,38
6	HFO Circulating Pump	3500	0,903505732	Rp 2.847.227,25
7	Filter	4800	0,997366457	Rp 1.837.124,22
8	ME Injection Pump	2200	0,975642715	Rp 10.376.267,67
9	ME Injection Valve	1700	0,921599044	Rp 12.804.234,99
Total				Rp 47.415.934,85

Based on the summary in **Table 4.25.** the maintenance cost on Fuel Oil System for 5 years is Rp. 47.415.934,85.

CHAPTER V
CONCLUSION AND SUGGESTION

5.1. Conclusion

In this final project used Reliability-Centered Maintenance method in causal analysis as well as determining the proper maintenance type of each failure mode which become the object of analysis. In this final project, failure mode is a list of historical repair or damage list that has happened and possibly happened to MV. Kendari I during the year 2011-2017. Based on qualitative and quantitative analysis, the following results are obtained :

1. Based on the analysis of FMECA, the components that can cause failure on Fuel Oil System on MV.Kendari I include HFO Transfer Pump, MDO Transfer Pump, Separator, HFO Feeder Pump, HFO Circulating Pump, Filter, Main Engine Injection Pump, and Main Engine Injection Valve.
2. There is one type of maintenance activity category (task categories) performed in the tasklist implementation. Category A with 43 types of tasklist.
3. In the type of task categories, there are 43 types of tasklist obtained based on maintenance task allocation and planning analysis. Where percentage of type maintenace of each failure mode (task type) :
    - Preventive Maintenance (PM) is 41.8%
    - Condition Monitoring (CM) was 30.2%
    - Failure Finding (FF) is 27.9%.
4. Summary of optimum maintenance cost for each component on Fuel Oil System on MV. Kendari I as follows :
    - HFO Transfer Pump has tp is worth 3500 hours with minimum estimated cost of Rp. 346.017,00.
    - MDO Transfer Pump has tp is worth 3500 hours with minimum estimated cost of Rp. 363.019,00.
    - Separator has tp is worth 1700 hours with minimum estimated cost of Rp. 518.342,00.
    - Heater has tp is worth 4400 hours with minimum estimated cost of Rp. 31.354,00.
    - HFO Feeder Pump has tp is worth 3500 hours with minimum estimated cost of Rp. 350.380,00.

- HFO Circulating Pump has tp is worth 3500 hours with minimum estimated cost of Rp. 346.017,00.
- Filter has tp is worth 4800 hours with minimum estimated cost of Rp. 30.619,00.
- Main Engine Injection Pump has tp is worth 2200 hours with minimum estimated cost of Rp. 792.632,00.
- Main Engine Injection Valve has tp is worth 1700 hours with minimum estimated cost of Rp. 755.806,00.

5.2. Suggestion

Based on the results of this thesis, there are still many things that become consideration and improvement for the development of more accurate research results. With the results of analysis and recommendations of this maintenance, is expected to be one improvement in maintenance activities for Fuel Oil System on MV. Kendari I PT Meratus Line. Some of the things that can be done are as follows :

1. It is expected that in the future PT Meratus Line, in particular maintenance division perform maintenance activities in accordance with the applicable provisions of both manufacturing, Class, and additional maintenance recommendations in overcoming any failure that occurs exactly at the time of maintenance recommendations.
2. In the development of this research required more specific failure data for Fuel Oil System on MV. Kendari I.
3. In the quantitative data processing, variations in the addition of operating hours can be implemented with a narrower distance, so that the reliability value of certain operating hours of each component can be identified more specifically.

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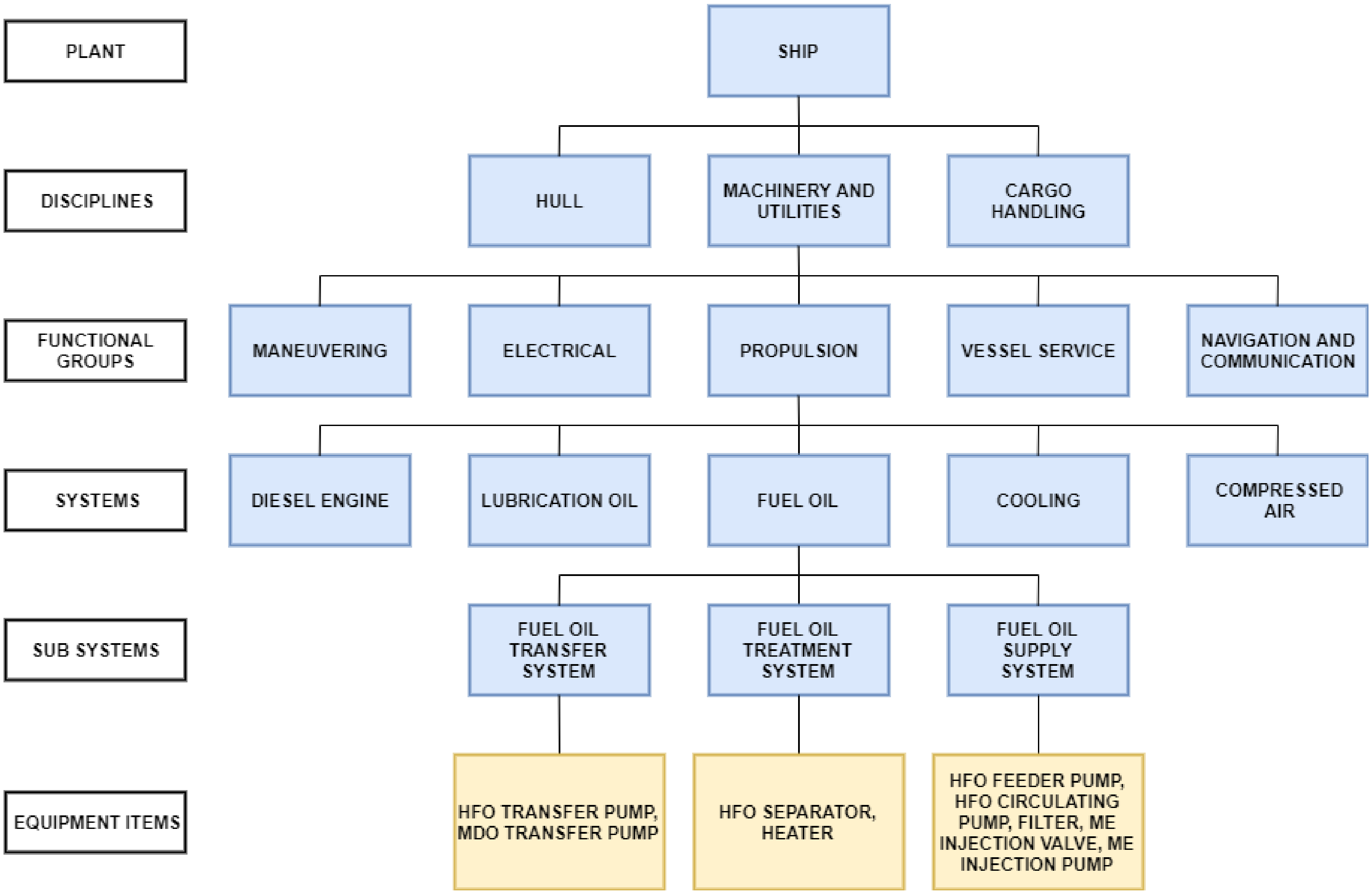
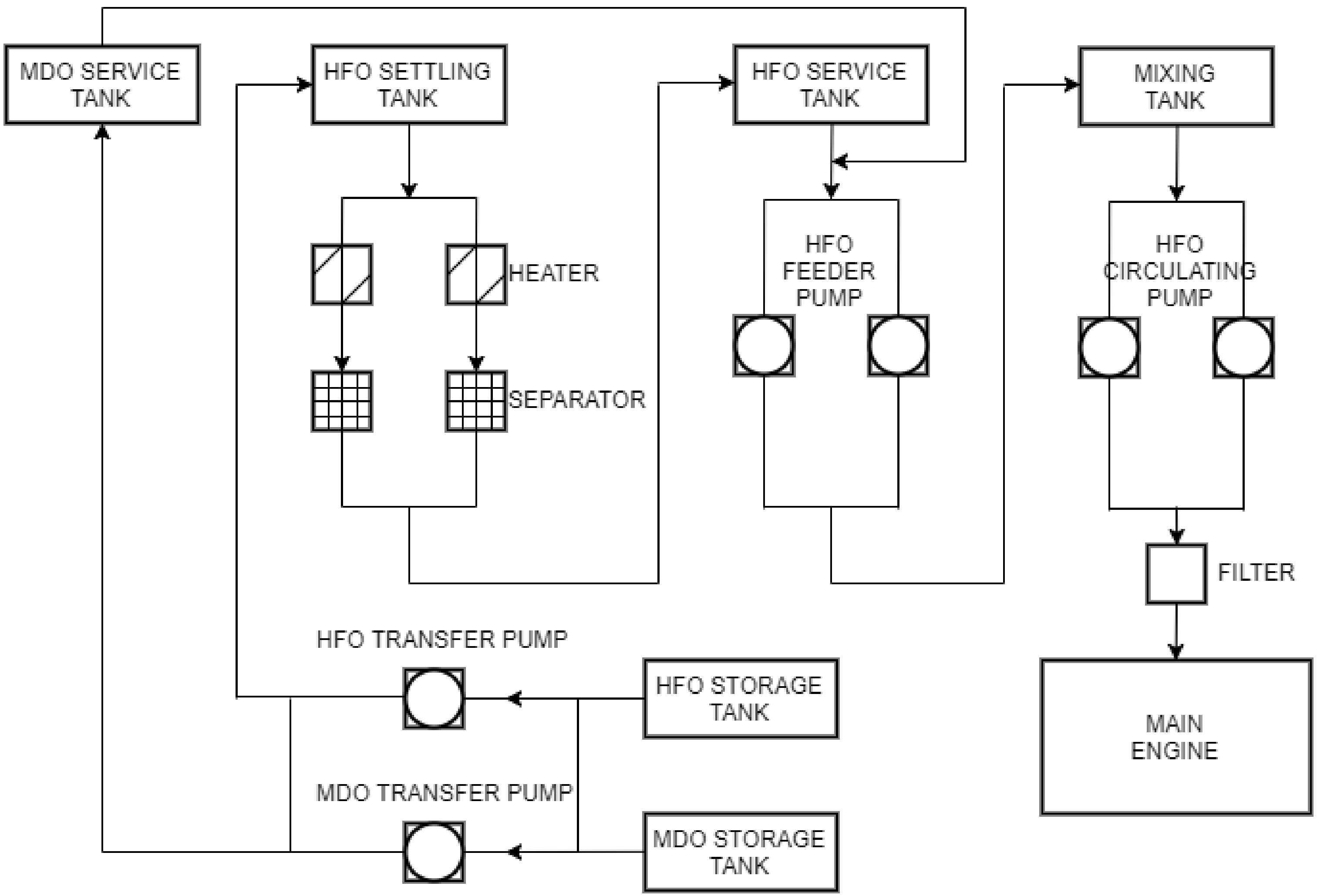
APPENDIX A


PLANT
DISCIPLINES
FUNCTIONAL GROUPS
SYSTEMS
SUB SYSTEMS
EQUIPMENT ITEMS
SHIP
HULL
MACHINERY AND UTILITIES
CARGO HANDLING
MANEUVERING
ELECTRICAL
PROPULSION
VESSEL SERVICE
NAVIGATION AND COMMUNICATION
DIESEL ENGINE
LUBRICATION OIL
FUEL OIL
COOLING
COMPRESSED AIR
FUEL OIL TRANSFER SYSTEM
FUEL OIL TREATMENT SYSTEM
FUEL OIL SUPPLY SYSTEM
HFO TRANSFER PUMP, MDO TRANSFER PUMP
HFO SEPARATOR, HEATER
HFO FEEDER PUMP, HFO CIRCULATING PUMP, FILTER, ME INJECTION VALVE, ME INJECTION PUMP



MDO SERVICE TANK
HFO SETTLING TANK
HFO SERVICE TANK
MIXING TANK
HEATER
SEPARATOR
HFO FEEDER PUMP
HFO CIRCULATING PUMP
FILTER
MAIN ENGINE
HFO TRANSFER PUMP
HFO STORAGE TANK
MDO TRANSFER PUMP
MDO STORAGE TANK

Severity Level	Descriptions for Severity Level	Definition for Severity Level	Applicable to Functional Groups for
1	Minor, Negligible	Function is not affected, no significant operational delays. Nuisance.	Propulsion Directional Control Drilling Position Mooring (Station Keeping) Hydrocarbon Production and Processing Import and Export Functions
2	Major, Marginal, Moderate	Function is not affected, however, failure detection/corrective measures not functional. OR Function is reduced, resulting in operational delays.	
3	Critical, Hazardous, Significant	Function is reduced, or damaged machinery, significant operational delays.	
4	Catastrophic, Critical	Complete loss of function.	

Severity Level	Descriptions for Severity Level	Definition for Severity Level	Applicable to Functional Groups for
1	Minor, Negligible	Little or no response necessary.	Loss of Containment
2	Major, Marginal, Moderate	Limited response of short duration.	
3	Critical, Hazardous, Significant	Serious/significant commitment of resources and personnel.	
4	Catastrophic, Critical	Complete loss of containment. Full scale response of extended duration to mitigate effects on environment.	

Severity Level	Descriptions for Severity Level	Definition for Severity Level	Applicable to Functional Groups for
1	Minor, Negligible	Minor impact on personnel/No impact on public.	Safety
2	Major, Marginal, Moderate	Professional medical treatment for personnel/No impact on public.	
3	Critical, Hazardous, Significant	Serious injury to personnel/Limited impact on public.	
4	Catastrophic, Critical	Fatalities to personnel/Serious impact on public.	

Severity Level	Descriptions for Severity Level	Definition for Severity Level	Applicable to Functional Groups for
1	Minor, Negligible	No damage to affected equipment or compartment, no significant operational delays.	Explosion/Fire
2	Major, Marginal, Moderate	Affected equipment is damaged, operational delays.	
3	Critical, Hazardous, Significant	An occurrence adversely affecting the vessel's seaworthiness or fitness for service or route.	
4	Catastrophic, Critical	Loss of vessel or results in total constructive loss.	

BOTTOM-UP FMECA WORKSHEET											
No:	Description: HFO Transfer Pump										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
1.1	Falls off while running	Pump motor failure Pump motor control error	Random	No fuel flow Start of MDO transfer pump and resume function	HFO transfer pump does not produce capacity of 30 m3/h at the time of operation.	It can not be used for operation	Propulsion	Level 1	Probable	Medium	Switch to MDO transfer pump
1.2	Falls to start on demand	Pump motor failure Pump motor control error	Random	No fuel flow Start of MDO transfer pump and resume function	HFO transfer pump does not produce capacity of 30 m3/h at the time of operation.	It can not be used for operation	Propulsion	Level 1	Frequent	Medium	Switch to MDO transfer pump
1.3	Operates with degraded performance (low output)	Scored thrust plate Worn/damaged screw pump Electrical motor Leak/rupture of pump housing Suction blockage HFO viscosity to low	Wear-out	Insufficient pressure or flow Pressure alarm alerts crew Start of standby pump and resume function	HFO transfer pump produces less than capacity of 30 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Probable	Medium	Switch to MDO transfer pump

1.4	External leakage	Mechanical seal worn out Cracks in housing	Wear-out	Release of lube oil in machinery space If leak is large, standby pump will start and resume function	HFO transfer pump produces less than capacity of 30 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Frequent	Medium	It is very likely the oil leak is detected by crew
1.5	Vibration and Noise. The pump vibrates and the sound which is very noisy	Screw Pump worn out Cavitation happened Pump foundation is not good	Wear-out	Pump breakdown hazard	No effect	None	Propulsion	Level 1	Frequent	Medium	Crew will hear sound
1.6	Electrical motor failure	Overheat; Pump or motor bearing wear; Wiring; Starter Overload	Random	No fuel flow Start of MDO transfer pump and resume function	HFO transfer pump produces less than capacity of 30 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Frequent	Medium	Switch to MDO transfer pump

BOTTOM-UP FMECA WORKSHEET											
No:	Description: MDO Transfer Pump										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
2.1	Falls off while running	Pump motor failure Pump motor control error	Random	No fuel flow Start of HFO transfer pump and resume function	MDO transfer pump does not produce capacity of 12 m3/h at the time of operation.	It can not be used for operation	Propulsion	Level 1	Probable	Medium	Switch to HFO transfer pump
2.2	Falls to start on demand	Pump motor failure Pump motor control error	Random	No fuel flow Start of HFO transfer pump and resume function	MDO transfer pump does not produce capacity of 12 m3/h at the time of operation.	It can not be used for operation	Propulsion	Level 1	Frequent	Medium	Switch to HFO transfer pump
2.3	Operates with degraded performance (low output)	Scored thrust plate Worn/damaged screw pump Electrical motor Leak/rupture of pump housing Suction blockage HFO viscosity to low	Wear-out	Insufficient pressure or flow Pressure alarm alerts crew Start of standby pump and resume function	MDO transfer pump produces less than capacity of 12 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Probable	Medium	Switch to HFO transfer pump

2.4	External leakage	Mechanical seal worn out Cracks in housing	Wear-out	Release of lube oil in machinery space If leak is large, standby pump will start and resume function	MDO transfer pump produces less than capacity of 12 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Frequent	Medium	It is very likely the oil leak is detected by crew
2.5	Vibration and Noise. The pump vibrates and the sound which is very noisy	Screw Pump worn out Cavitation happened Pump foundation is not good	Wear-out	Pump breakdown hazard	No effect	None	Propulsion	Level 1	Frequent	Medium	Crew will hear sound
2.6	Electrical motor failure	Overheat; Pump or motor bearing wear; Wiring; Starter Overload	Random	No fuel flow Start of HFO transfer pump and resume function	MDO transfer pump produces less than capacity of 12 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Frequent	Medium	Switch to HFO transfer pump

BOTTOM-UP FMECA WORKSHEET											
No:	Description: Separator										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
3.1	Rotation stops (fail to start)	Insufficient lubrication seizure of rotation parts Drive / Bearing failures Electric motor controls failure Flat belt break Separator brake can't be released	Random	No separation (flters solids and water) Alarm if Viscosity is not met. Separator auto switch off.	Separator does not separate the dissolved water, impurities and sludge from the fuel oil with capacity of 1.5 m3/h.	There are excess volume of dissolved water, impurities and sludge	Propulsion	Level 1	Frequent	Medium	Switch to separator 2
3.2	Rotation degraded (low speed)	Insufficient lubrication Flat belt break Electric motor controls failure	Wear-out	Poor separation, low HFO output Stop separator 1 switch to separator 2.	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Propulsion	Level 1	Frequent	Medium	Switch to separator 2
3.3	Centripedal pumping fails	Coupling worn out Boshing worn out Belt pulley worn out	Wear-out	Low flow rate of light or heavy liquid	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Propulsion	Level 1	Probable	Medium	Switch to separator 2

3.4	Does not completely discharge sludge	Bowl Stuck Solenoid valve fails to open Clogging of disk or other parts No operating water	Wear-out	Separator fails to function if it contains excessive sludge Can affect other functions	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Propulsion	Level 1	Frequent	Medium	Discharge detector alarm (e) Water go-through is hidden not checked manually in the service tank (h)
3.5	Internal Leakage	HFO quality Unknown	Random	Leak detection for treated liquid leading through sludge or water outlet will trigger alarm Water contamination is undetected and will lead to day tanks	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Propulsion	Level 3	Frequent	High	Water go through is hidden if not checked manually in the service tank (h)
3.6	External leakage	Flunge / seals Various o-rings Valves	Wear-out	Release of lube oil in machinery space.	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Propulsion	Level 1	Frequent	Medium	It is very likely the oil leak is detected by crew (e)
3.7	Vibration and noise	Separator and pump rotating parts and bearing	Wear-out	Separator failure hazard	No effect	None	Propulsion	Level 1	Frequent	Medium	Vibraton sensor Crew will hear sound (e)

BOTTOM-UP FMECA WORKSHEET											
No:	Description: Heater										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
4.1	Heat Incorrect heating	Temperature controllers not functioning properly	Random	Separator operates at degradated separation perrformance (filter solids and water) HFO viscosityis abnormal separator temperature sensor will cause alarm if Viscosity is not met. Separator auto switch off.	Heater heating the fuel less than between 80-85oc.	The viscosity of HFO increasing	Propulsion	Level 1	Frequent	Medium	Check valve economizer

BOTTOM-UP FMECA WORKSHEET											
No:	Description: HFO Feeder Pump										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
5.1	Falls off while running	Pump motor failure Pump motor control error	Random	No fuel flow Start of standby pump and resume function	HFO feeder pump does not produce capacity of 1.5 m3/h at the time of operation.	It can not be used for operation	Propulsion	Level 1	Probable	Medium	Switch to stand by gear pump
5.2	Falls to start on demand	Pump motor failure Pump motor control error	Random	No fuel flow Start of standby pump and resume function	HFO feeder pump does not produce capacity of 1.5 m3/h at the time of operation.	It can not be used for operation	Propulsion	Level 1	Frequent	Medium	Switch to stand by gear pump
5.3	Operates with degraded performance (low output)	Scored thrust plate Worn/damaged gear pump Electrical motor Leak/rupture of pump housing Suction blockage HFO viscosity to low	Wear-out	Insufficient pressure or flow Pressure alarm alerts crew Start of standby pump and resume function	HFO feeder pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Probable	Medium	Switch to stand by gear pump

5.4	External leakage	Mechanical seal worn out Cracks in housing	Wear-out	Release of lube oil in machinery space If leak is large, standby pump will start and resume function	HFO feeder pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Frequent	Medium	It is very likely the oil leak is detected by crew
5.5	Vibration and Noise. The pump vibrates and the sound which is very noisy	Gear Pump worn out Cavitation happened Pump foundation is not good	Wear-out	Pump breakdown hazard	No effect	None	Propulsion	Level 1	Frequent	Medium	Crew will hear sound
5.6	Electrical motor failure	Overheat; Pump or motor bearing wear; Wiring; Starter Overload	Random	No fuel flow Start of standby pump and resume function	HFO feeder pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Frequent	Medium	Switch to stand by gear pump

BOTTOM-UP FMECA WORKSHEET											
No:	Description: HFO Circulating Pump										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
6.1	Falls off while running	Pump motor failure Pump motor control error	Random	No fuel flow Start of standby pump and resume function	HFO circulating pump does not produce capacity of 1.5 m3/h at the time of operation.	It can not be used for operation	Propulsion	Level 1	Probable	Medium	Switch to stand by gear pump
6.2	Falls to start on demand	Pump motor failure Pump motor control error	Random	No fuel flow Start of standby pump and resume function	HFO circulating pump does not produce capacity of 1.5 m3/h at the time of operation.	It can not be used for operation	Propulsion	Level 1	Frequent	Medium	Switch to stand by gear pump
6.3	Operates with degraded performance (low output)	Scored thrust plate Worn/damaged gear pump Electrical motor Leak/rupture of pump housing Suction blockage HFO viscosity to low	Wear-out	Insufficient pressure or flow Pressure alarm alerts crew Start of standby pump and resume function	HFO circulating pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Probable	Medium	Switch to stand by gear pump

6.4	External leakage	Mechanical seal worn out Cracks in housing	Wear-out	Release of lube oil in machinery space If leak is large, standby pump will start and resume function	HFO circulating pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Frequent	Medium	It is very likely the oil leak is detected by crew
6.5	Vibration and Noise. The pump vibrates and the sound which is very noisy	Gear Pump worn out Cavitation happened Pump foundation is not good	Wear-out	Pump breakdown hazard	No effect	None	Propulsion	Level 1	Frequent	Medium	Crew will hear sound
6.6	Electrical motor failure	Overheat; Pump or motor bearing wear; Wiring; Starter Overload	Random	No fuel flow Start of standby pump and resume function	HFO circulating pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Propulsion	Level 1	Frequent	Medium	Switch to stand by gear pump

BOTTOM-UP FMECA WORKSHEET											
No:	Description: Filter										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
7.1	Accumulation of residues clogging	Particles in HFO	Wear-out	Auto clean Bypass to stand by filter	Filters screens out dirt and rust particles from fuel with size less than 13 milimicron.	Fuel still dirty and contain rust particles	Propulsion	Level 1	Frequent	Medium	Change the filter
7.2	Internal leak / filter	Corrosion Filter worn	Wear-out	Micro particles passing filter	Filter does not screens out dirt and rust particles from the fuel with size 13 milimicron.	There are excess volume of rust particles	Propulsion	Level 2	Frequent	High	Change the filter
7.3	Internal leak sludge discharge valve (HFO filter)	Corrosion Sea valve worn out	Wear-out	Fuel oil is passing the discharge valve	Filters screens out dirt and rust particles from fuel with size less than 13 milimicron.	Fuel still dirty and contain rust particles	Propulsion	Level 1	Frequent	Medium	Check the discharge valve
7.4	External leakage	Crack in packing housing The binding is skewed	Wear-out	Release of FO in machinery space	Filters screens out dirt and rust particles from fuel with size less than 13 milimicron.	Fuel still dirty and contain rust particles	Propulsion	Level 1	Frequent	Medium	Change the filter

BOTTOM-UP FMECA WORKSHEET											
No:	Description: ME Injection Pump										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
8.1	Injetion pump fails to operate (for one cylinder)	Injection pump exessive leak	Random	No combustion of cylinder	ME injection pump does not deliver fuel into the injector with pressure of 380 bar.	Engine runs not well Potential for engine damage	Propulsion	Level 3	Frequent	High	Will be noticed by crew
8.2	Incorrect fuel injection pressure	Injection pump has play inside or internal leakage Incorrect injection needle opening pressure set Injection valve spring worn and tired Cavitation	Wear-out	By lowering the discharge pressure, fuel is delivered earlier to the combustion chamber, and continues for longer with increased droplet size Combustion occurs at a time uncorrelated to ideal cylinder pressure and temperature	ME injection pump deliver fuel into the injector with pressure less than 380 bar.	Reduce ME performance	Propulsion	Level 2	Frequent	High	Exhaust gas temperature changes Cylinder pressure changes Hidden (which cylinder) if small
8.3	Bad injection timing	Bad injection pump timing Injector needle jamming Valve spring fatigue	Random	Engine misfire	ME injection pump deliver fuel into the injector with pressure less than 380 bar.	Reduce ME performance	Propulsion	Level 2	Probable	High	Engine knock Discoloured exhaust

BOTTOM-UP FMECA WORKSHEET											
No:	Description: ME Injection Valve										
Item (1)	Failure Mode (2)	Failure Causes (3)	Failure Characteristic (4)	Local Effects (5)	Functional Failure (6)	End Effect (7)	Matrix (8)	Severity (9)	CL (10)	CR (11)	Failure Detection/Corrective Measures (12)
9.1	Injetion valve fails to operate (for one cylinder)	Injection valve clogged	Random	No combustion of cylinder	ME injection valve does not spray fuel into the engine cylinders with pressure of 380 bar.	Engine runs not well Potential for engine damage	Propulsion	Level 3	Frequent	High	Will be noticed by crew
9.2	Incorrect fuel volume	Injection valve leaking Injection valve dribbling	Wear-out	Bad mixing ratio of combustion air and fuel Thermal overload	ME injection valve spray fuel into the engine cylinders with pressure less than 380 bar.	Reduce ME performance	Propulsion	Level 2	Probable	High	Exhaust gas temperature changes
9.3	Incorrect atomisation	Holes of the injector nozzle are partly blocked Nozzle enlarged by erosion	Random	Poor fuel atomisation Power of cylinder sinks Hazard to damage the piston	ME injection valve spray fuel into the engine cylinders with pressure less than 380 bar.	Reduce ME performance	Propulsion	Level 2	Frequent	High	Evident if spray causes incorrect combustion Piston damage can occur hidden
9.4	External leakage	Body or mechanical joint leak in injector body	Wear-out	FO leaks out of engine FO contaminates lubrication oil	ME injection valve spray fuel into the engine cylinders with pressure less than 380 bar.	Reduce ME performance	Propulsion	Level 1	Probable	Medium	It is very likely the FO leak is detected by crew

No.		Description: HFO Transfer Pump											
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)			
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition
1.1	Falls off while running	Random	H	No fuel flow Start of MDO transfer pump and resume function	HFO transfer pump does not produce capacity of 30 m3/h at the time of operation.	It can not be used for operation	Level 1	Probable	Medium	Functional test of the standby pump and pump controls	Occasional	Low	In the operational period
1.2	Falls to start on demand	Random	H	No fuel flow Start of MDO transfer pump and resume function	HFO transfer pump does not produce capacity of 30 m3/h at the time of operation.	It can not be used for operation	Level 1	Frequent	Medium	Starter inspection	Probable	Medium	In the operational period
1.3	Operates with degraded performance (low output)	Wear-out	E	Insufficient pressure or flow Pressure alarm alerts crew Start of standby pump and resume function	HFO transfer pump produces less than capacity of 30 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Probable	Medium	Electric motor overhaul	Occasional	Low	In the operational period

1.4	External leakage	Wear-out	E	Release of lube oil in machinery space If leak is large, standby pump will start and resume function	HFO transfer pump produces less than capacity of 30 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Frequent	Medium	Optically check for external leakage	Probable	Medium	In the operational period
1.5	Vibration and Noise. The pump vibrates and the sound which is very noisy	Wear-out	H	Pump breakdown hazard	No effect	None	Level 1	Frequent	Medium	Allignment check of pump and motor	Probable	Medium	In the operational period
1.6	Electrical motor failure	Random	H	No fuel flow Start of MDO transfer pump and resume function	HFO transfer pump produces less than capacity of 30 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Frequent	Medium	Temperature check of bearing temperatures	Probable	Medium	In the operational period

No.		Description: MDO Transfer Pump											
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)			
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition
2.1	Falls off while running	Random	H	No fuel flow Start of HFO transfer pump and resume function	MDO transfer pump does not produce capacity of 12 m3/h at the time of operation.	It can not be used for operation	Level 1	Probable	Medium	Functional test of the standby pump and pump controls	Occasional	Low	In the operational period
2.2	Falls to start on demand	Random	H	No fuel flow Start of HFO transfer pump and resume function	MDO transfer pump does not produce capacity of 12 m3/h at the time of operation.	It can not be used for operation	Level 1	Frequent	Medium	Starter inspection	Probable	Medium	In the operational period
2.3	Operates with degraded performance (low output)	Wear-out	E	Insufficient pressure or flow Pressure alarm alerts crew Start of standby pump and resume function	MDO transfer pump produces less than capacity of 12 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Probable	Medium	Electric motor overhaul	Occasional	Low	In the operational period

2.4	External leakage	Wear-out	E	Release of lube oil in machinery space If leak is large, standby pump will start and resume function	MDO transfer pump produces less than capacity of 12 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Frequent	Medium	Optically check for external leakage	Probable	Medium	In the operational period
2.5	Vibration and Noise. The pump vibrates and the sound which is very noisy	Wear-out	H	Pump breakdown hazard	No effect	None	Level 1	Frequent	Medium	Allignment check of pump and motor	Probable	Medium	In the operational period
2.6	Electrical motor failure	Random	H	No fuel flow Start of HFO transfer pump and resume function	MDO transfer pump produces less than capacity of 12 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Frequent	Medium	Temperature check of bearing temperatures	Probable	Medium	In the operational period

No.		Description: Separator											
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)			
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition
3.1	Rotation stops (fail to start)	Random	H	No separation (flters solids and water) Alarm if Viscosity is not met. Separator auto switch off.	Separator does not separate the dissolved water, impurities and sludge from the fuel oil with capacity of 1.5 m3/h.	There are excess volume of dissolved water, impurities and sludge	Level 1	Frequent	Medium	Functional test of the standby purifier and purifier controls	Probable	Medium	In the operational period
3.2	Rotation degraded (low speed)	Wear-out	E	Poor separation, low HFO output Stop separator 1 switch to separator 2.	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Level 1	Frequent	Medium	Routine check according manual	Probable	Medium	In the operational period
3.3	Centripedal pumping fails	Wear-out	E	Low flow rate of light or heavy liquid	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Level 1	Probable	Medium	Routine check according manual	Occasional	Low	In the operational period

3.4	Does not completely discharge sludge	Wear-out	E	Separator fails to function if it contains excessive sludge Can affect other functions	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Level 1	Frequent	Medium	Open and clean bowl	Probable	Medium	In the operational period
3.5	Internal Leakage	Random	H	Leak detection for treated liquid leading through sludge or water outlet will trigger alarm Water contamination is undetected and will lead to day tanks	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Level 3	Frequent	High	Check service tank for water with water finding paste	Probable	High	In the operational period
3.6	External leakage	Wear-out	E	Release of lube oil in machinery space.	Separator separate the dissolved water, impurities and sludge from the fuel oil with capacity less than of 1.5 m3/h.	Fuel still contain dissolved water, impurities and sludge	Level 1	Frequent	Medium	Optically check for external leakage	Probable	Medium	In the operational period
3.7	Vibration and noise	Wear-out	E	Separator failure hazard	No effect	None	Level 1	Frequent	Medium	Vibration and noise soundcheck	Probable	Medium	In the operational period

No.		Description: Heater											
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)			
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition
4.1	Heat Incorrect heating	Random	H	Separator operates at degradated separation perrformance (filter solids and water) HFO viscosityis abnormal separator temperature sensor will cause alarm if Viscosity is not met. Separator auto switch off.	Heater heating the fuel less than between 80-85oc.	The viscosity of HFO increasing	Level 1	Frequent	Medium	Check and record temperature	Probable	Medium	In the operational period

No.		Description: HFO Feeder Pump												
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)				
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition	
5.1	Falls off while running	Random	H	No fuel flow Start of standby pump and resume function	HFO feeder pump does not produce capacity of 1.5 m3/h at the time of operation.	It can not be used for operation	Level 1	Probable	Medium	Functional test of the standby pump and pump controls	Occasional	Low	In the operational period	
5.2	Falls to start on demand	Random	H	No fuel flow Start of standby pump and resume function	HFO feeder pump does not produce capacity of 1.5 m3/h at the time of operation.	It can not be used for operation	Level 1	Frequent	Medium	Starter inspection	Probable	Medium	In the operational period	
5.3	Operates with degraded performance (low output)	Wear-out	E	Insufficient pressure or flow Pressure alarm alerts crew Start of standby pump and resume function	HFO feeder pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Probable	Medium	Electric motor overhaul	Occasional	Low	In the operational period	

5.4	External leakage	Wear-out	E	Release of lube oil in machinery space If leak is large, standby pump will start and resume function	HFO feeder pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Frequent	Medium	Optically check for external leakage	Probable	Medium	In the operational period
5.5	Vibration and Noise. The pump vibrates and the sound which is very noisy	Wear-out	H	Pump breakdown hazard	No effect	None	Level 1	Frequent	Medium	Allignment check of pump and motor	Probable	Medium	In the operational period
5.6	Electrical motor failure	Random	H	No fuel flow Start of standby pump and resume function	HFO feeder pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Frequent	Medium	Temperature check of bearing temperatures	Probable	Medium	In the operational period

No.		Description: HFO Circulating Pump											
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)			
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition
6.1	Falls off while running	Random	H	No fuel flow Start of standby pump and resume function	HFO circulating pump does not produce capacity of 1.5 m3/h at the time of operation.	It can not be used for operation	Level 1	Probable	Medium	Functional test of the standby pump and pump controls	Occasional	Low	In the operational period
6.2	Falls to start on demand	Random	H	No fuel flow Start of standby pump and resume function	HFO circulating pump does not produce capacity of 1.5 m3/h at the time of operation.	It can not be used for operation	Level 1	Frequent	Medium	Starter inspection	Probable	Medium	In the operational period
6.3	Operates with degraded performance (low output)	Wear-out	E	Insufficient pressure or flow Pressure alarm alerts crew Start of standby pump and resume function	HFO circulating pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Probable	Medium	Electric motor overhaul	Occasional	Low	In the operational period

6.4	External leakage	Wear-out	E	Release of lube oil in machinery space If leak is large, standby pump will start and resume function	HFO circulating pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Frequent	Medium	Optically check for external leakage	Probable	Medium	In the operational period
6.5	Vibration and Noise. The pump vibrates and the sound which is very noisy	Wear-out	H	Pump breakdown hazard	No effect	None	Level 1	Frequent	Medium	Allignment check of pump and motor	Probable	Medium	In the operational period
6.6	Electrical motor failure	Random	H	No fuel flow Start of standby pump and resume function	HFO circulating pump produces less than capacity of 1.5 m3/h at the time of operation.	It take more times to deliver the fuel	Level 1	Frequent	Medium	Temperature check of bearing temperatures	Probable	Medium	In the operational period

No.		Description: Filter											
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)			
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition
7.1	Accumulation of residues clogging	Wear-out	E	Auto clean Bypass to stand by filter	Filters screens out dirt and rust particles from fuel with size less than 13 milimicron.	Fuel still dirty and contain rust particles	Level 1	Frequent	Medium	Constantly observe and record pressure difference self-cleaning intervals	Probable	Medium	In the operational period
7.2	Internal leak / filter	Wear-out	E	Micro particles passing filter	Filter does not screens out dirt and rust particles from the fuel with size 13 milimicron.	There are excess volume of rust particles	Level 2	Frequent	High	Check for leakage regularly	Probable	High	In the operational period
7.3	Internal leak sludge discharge valve (HFO filter)	Wear-out	E	Fuel oil is passing the discharge valve	Filters screens out dirt and rust particles from fuel with size less than 13 milimicron.	Fuel still dirty and contain rust particles	Level 1	Frequent	Medium	Routine inspection with manual cleaning	Probable	Medium	In the operational period
7.4	External leakage	Wear-out	E	Release of FO in machinery space	Filters screens out dirt and rust particles from fuel with size less than 13 milimicron.	Fuel still dirty and contain rust particles	Level 1	Frequent	Medium	Check for leakage regularly	Probable	Medium	In the operational period

No.		Description: ME Injection Pump											
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)			
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition
8.1	Injetion pump fails to operate (for one cylinder)	Random	H	No combustion of cylinder	ME injection pump does not deliver fuel into the injector with pressure of 380 bar.	Engine runs not well Potential for engine damage	Level 3	Frequent	High	Disassembly, Cleaning and check as advised by ME manual	Probable	High	In the operational period
8.2	Incorrect fuel injection pressure	Wear-out	E	By lowering the discharge pressure, fuel is delivered earlier to the combustion chamber, and continues for longer with increased droplet size Combustion occurs at a time uncorrelated to ideal cylinder pressure and temperature	ME injection pump deliver fuel into the injector with pressure less than 380 bar.	Reduce ME performance	Level 2	Frequent	High	Cylinder pressure measurement	Probable	High	In the operational period
8.3	Bad injection timing	Random	H	Engine misfire	ME injection pump deliver fuel into the injector with pressure less than 380 bar.	Reduce ME performance	Level 2	Probable	High	Cylinder pressure measurement	Occasional	Medium	In the operational period

No.		Description: ME Injection Valve											
Item (1)	Failure Mode (2)	Failure Char. (3)	H/E (4)	Effect (5)			Risk Characterization (6)			Task Selection (7)			
				Local	Functional Failure	End	Severity	CL	CR	Proposed Action	PL	PR	Disposition
9.1	Injetion valve fails to operate (for one cylinder)	Random	H	No combustion of cylinder	ME injection valve does not spray fuel into the engine cylinders with pressure of 380 bar.	Engine runs not well Potential for engine damage	Level 3	Frequent	High	Disassembly, Cleaning and check as advised by ME manual	Probable	High	In the operational period
9.2	Incorrect fuel volume	Wear-out	E	Bad mixing ratio of combustion air and fuel Thermal overload	ME injection valve spray fuel into the engine cylinders with pressure less than 380 bar.	Reduce ME performance	Level 2	Probable	High	Exhaust gas temperature measurement	Occasional	Medium	In the operational period
9.3	Incorrect atomisation	Random	H	Poor fuel atomisation Power of cylinder sinks Hazard to damage the piston	ME injection valve spray fuel into the engine cylinders with pressure less than 380 bar.	Reduce ME performance	Level 2	Frequent	High	Drawing out fuel injection valve, valve check	Probable	High	In the operational period
9.4	External leakage	Wear-out	E	FO leaks out of engine FO contaminates lubrication oil	ME injection valve spray fuel into the engine cylinders with pressure less than 380 bar.	Reduce ME performance	Level 1	Probable	Medium	Check for leakage regularly	Occasional	Low	In the operational period

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :	Category A						
Functional Group :	Propulsion						
System :	Fuel Oil						
Sub System :	Fuel Oil Transfer System						
Equipment Item :	HFO Transfer Pump						
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Functional test of the standby pump and pump controls	FF	1.1	Occasional	Low	Once per voyage	-	This duty pump operating context is to run until a failure occurs, then standby pump is started
Starter inspection	FF	1.2	Probable	Medium	Once per voyage	-	-
Electric motor overhaul	PM	1.3	Occasional	Low	Every 24 months	-	For duty pumps only
Optically check for external leakage	PM	1.4	Probable	Medium	Every 3 months	-	-
Allignment check of pump and motor	CM	1.5	Probable	Medium	Every 6 months	-	-
Temperature check of bearing temperatures	CM	1.6	Probable	Medium	Every 1 months	-	-

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :	Category A						
Functional Group :	Propulsion						
System :	Fuel Oil						
Sub System :	Fuel Oil Transfer System						
Equipment Item :	MDO Transfer Pump						
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Functional test of the standby pump and pump controls	FF	2.1	Occasional	Low	Once per voyage	-	This duty pump operating context is to run until a failure occurs, then standby pump is started
Starter inspection	FF	2.2	Probable	Medium	Once per voyage	-	-
Electric motor overhaul	PM	2.3	Occasional	Low	Every 24 months	-	For duty pumps only
Optically check for external leakage	PM	2.4	Probable	Medium	Every 3 months	-	-
Allignment check of pump and motor	CM	2.5	Probable	Medium	Every 6 months	-	-
Temperature check of bearing temperatures	CM	2.6	Probable	Medium	Every 1 months	-	-

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :	Category A						
Functional Group :	Propulsion						
System :	Fuel Oil						
Sub System :	Fuel Oil Treatment System						
Equipment Item :	Separator						
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Functional test of the standby purifier and purifier controls	FF	3.1	Probable	Medium	Once per voyage	-	According maintenance manual
Routine check according manual	PM	3.2	Probable	Medium	Every 6 months	-	-
Routine check according manual	PM	3.3	Occasional	Low	Every 6 months	-	-
Open and clean bowl	PM	3.4	Probable	Medium	Every 3 months	-	-
Check service tank for water with water finding paste	FF	3.5	Probable	High	Perform before voyage and after arrival	-	-
Optically check for external leakage	PM	3.6	Probable	Medium	Every 12 months	-	-
Vibration and noise soundcheck	CM	3.7	Probable	Medium	Every 3 months	-	-

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :	Category A						
Functional Group :	Propulsion						
System :	Fuel Oil						
Sub System :	Fuel Oil Treatment System						
Equipment Item :	Heater						
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Check and record temperature	CM	4.1	Probable	Medium	Every 3 months	-	-

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :	Category A						
Functional Group :	Propulsion						
System :	Fuel Oil						
Sub System :	Fuel Oil Supply System						
Equipment Item :	HFO Feeder Pump						
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Functional test of the standby pump and pump controls	FF	5.1	Occasional	Low	Once per voyage	-	This duty pump operating context is to run until a failure occurs, then standby pump is started
Starter inspection	FF	5.2	Probable	Medium	Once per voyage	-	-
Electric motor overhaul	PM	5.3	Occasional	Low	Every 24 months	-	For duty pumps only
Optically check for external leakage	PM	5.4	Probable	Medium	Every 3 months	-	-
Allignment check of pump and motor	CM	5.5	Probable	Medium	Every 6 months	-	-
Temperature check of bearing temperatures	CM	5.6	Probable	Medium	Every 1 months	-	-

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :	Category A						
Functional Group :	Propulsion						
System :	Fuel Oil						
Sub System :	Fuel Oil Supply System						
Equipment Item :	HFO Circulating Pump						
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Functional test of the standby pump and pump controls	FF	6.1	Occasional	Low	Once per voyage	-	This duty pump operating context is to run until a failure occurs, then standby pump is started
Starter inspection	FF	6.2	Probable	Medium	Once per voyage	-	-
Electric motor overhaul	PM	6.3	Occasional	Low	Every 24 months	-	For duty pumps only
Optically check for external leakage	PM	6.4	Probable	Medium	Every 3 months	-	-
Allignment check of pump and motor	CM	6.5	Probable	Medium	Every 6 months	-	-
Temperature check of bearing temperatures	CM	6.6	Probable	Medium	Every 1 months	-	-

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :		Category A					
Functional Group :		Propulsion					
System :		Fuel Oil					
Sub System :		Fuel Oil Supply System					
Equipment Item :		Filter					
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Constantly observe and record pressure difference self-cleaning intervals	CM	7.1	Probable	Medium	Daily with filter operation	-	-
Check for leakage regularly	PM	7.2	Probable	High	Every 1 month	-	Failure detection at ME filter
Routine inspection with manual cleaning	PM	7.3	Probable	Medium	Every 1 month	-	Frequency is depending on the back flushing cycles and can not be estimated without practical experience
Check for leakage regularly	PM	7.4	Probable	Medium	Every 1 month	-	-

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :		Category A					
Functional Group :		Propulsion					
System :		Fuel Oil					
Sub System :		Fuel Oil Supply System					
Equipment Item :		ME Injection Pump					
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Disassembly, Cleaning and check as advised by ME manual	FF	8.1	Probable	High	Every 6 months	-	According maintenance manual
Cylinder pressure measurement	CM	8.2	Probable	High	Once per voyage	-	Duration is assumed
Cylinder pressure measurement	PM	8.3	Occasional	Medium	Every 6 months	-	Duration is assumed

SUMMARY OF MAINTENANCE TASKS							
Maintenance Category :	Category A						
Functional Group :	Propulsion						
System :	Fuel Oil						
Sub System :	Fuel Oil Supply System						
Equipment Item :	ME Injection Valve						
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Current	Projected			
Disassembly, Cleaning and check as advised by ME manual	FF	9.1	Probable	High	Every 6 months	-	According maintenance manual
Exhaust gas temperature measurement	PM	9.2	Occasional	Medium	Every 1 month	-	Duration is assumed
Drawing out fuel injection valve, valve check	CM	9.3	Probable	High	Every 3 months	-	Duration is assumed
Check for leakage regularly	PM	9.4	Occasional	Low	Every 3 months	-	-

SUMMARY OF LOGIC TREE ANALYSIS														
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
1.1	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
1.2	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
1.3	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
1.4	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
1.5	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP
1.6	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP

SUMMARY OF LOGIC TREE ANALYSIS														
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
2.1	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
2.2	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
2.3	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
2.4	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
2.5	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP
2.6	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP

SUMMARY OF LOGIC TREE ANALYSIS														
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
3.1	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
3.2	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
3.3	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
3.4	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
3.5	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
3.6	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
3.7	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP

SUMMARY OF LOGIC TREE ANALYSIS															
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
4.1	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP

SUMMARY OF LOGIC TREE ANALYSIS														
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
5.1	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
5.2	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
5.3	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
5.4	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
5.5	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP
5.6	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP

SUMMARY OF LOGIC TREE ANALYSIS														
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
6.1	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
6.2	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
6.3	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
6.4	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
6.5	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP
6.6	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP

SUMMARY OF LOGIC TREE ANALYSIS															
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
7.1	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP
7.2	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
7.3	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
7.4	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP

SUMMARY OF LOGIC TREE ANALYSIS														
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
8.1	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
8.2	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP
8.3	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP

SUMMARY OF LOGIC TREE ANALYSIS														
Failure Mode	CCR	H/L	(A)	CMT	(B)	CAUSE	WI	(C1)	WO	(C2)	HID/EVD	LOF	FF	(D)
9.1	NO	STOP	STOP	NO	NID	WO	STOP	STOP	NO	NID	HID	YES	FF	STOP
9.2	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP
9.3	NO	STOP	STOP	YES	CM	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP
9.4	NO	STOP	STOP	NO	NID	WO	STOP	STOP	YES	PM	STOP	STOP	STOP	STOP

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The Author's name is Dimas Darmawan, born on 15 July 1996 in Gandusari, Blitar regency, East Java. As the youngest child from three siblings. Derived from a simple family with a Father named Didik Surdianto and Mother named Sunarsih. However, fortunate to have a formal education at SDN Gandusari 02, he continued his study at SMP Negeri 2 Gandusari, and SMAN 1 Garum. In 2014, author proceed to pursue bachelor degree at Department of Marine Engineering (Double Degree Program with Hochschule Wismar), Faculty of Marine Engineering, Institut Teknologi Sepuluh Nopember Surabaya specializes in Reliability, Availability, Management, and Safety field. During the study period, Author did activities in campus organizations such as: UKAFO ITS (2014-2015) and RAMS Laboratory (2017-2018). The Autor also joined in several event organizers such as Water Bike Marine Icon 2015, Public Relation Marine Icon 2016, and Technical Program Committee Maritime Safety International Conference 2018.

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Motto : "Just doing the right things rightly"